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ELECTRICAL
METERMEN'S HANDBOOK

ELECTRICAL METERMEN'S HANDBOOK

Revised and Edited by
Handbook Revision Committee *of the*
Meter *and* Service Committee
Edison Electric Institute

Sixth Edition

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PREFACE TO THE SIXTH EDITION

The Electrical Metermen's Handbook is intended to serve as a practical guide to experienced metermen in solving the great variety of problems encountered in their daily work, and to provide essential material in a complete, concise, orderly text which may prove useful in the training and development of new metermen. It also will serve supervisors and executives in giving them an overall view of the requirements for organizing and directing a modern meter department.

The first edition of the Electrical Metermen's Handbook was published under the direction of the Meter Committee of the National Electric Light Association in 1912. The original work was revised and published as the second edition in 1915. The third edition, a further revision of the original, containing considerable additional material, was published in 1917. The fourth edition, also revised, was published in 1923. In the fifth edition the previous material was rearranged in a more useful form, including new reference tables, and much of the data concerning meters manufactured prior to 1924 was omitted.

In the sixth edition, much new material has been added to show the most modern equipment, methods, and engineering practices. In addition, an appendix taken from the 1923 edition has been provided showing the essential data required in the maintenance of older meters which are still in general use. Except for this appendix, the material is, wherever practicable, in accordance with the latest standards of the Edison Electric Institute, Association of Edison Illuminating Companies, and American Standards Association.

Recognition is given to the splendid work done by those who prepared the earlier editions of this Handbook. Much which they have done has been carried forward into this latest edition and stands as a monument to their efforts.

Credit is given to the meter manufacturers for their cooperation in providing information on their products, to our fellow-workers who have assisted the Committee members in the preparation of the material, and to the editorial staff at EEI headquarters who assisted in the publication of the book.

It is anticipated that future editions will be prepared as new developments make it necessary. If any user of this Handbook has any suggestions which he believes would make future editions more useful or useable, such suggestions or comments or criticisms will be welcomed and should be sent to the *Editing Committee, Electrical Metermen's Handbook, Edison Electric Institute, 420 Lexington Avenue, New York 17, N. Y.*

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ELECTRICAL
METERMEN'S HANDBOOK

SECTION 1

THE METER DEPARTMENT

The meter department, as an important division of a utility company organization, must exemplify those fundamentals of service which inspire confidence. It must develop methods and train its personnel to assure customers, stockholders, executives, and the general public that all assigned functions will be performed in an orderly manner, with accuracy, brevity, safety, and economy.

FUNCTIONS

The meter department will cover some or all of the following functions: making service connections; installing, testing and maintaining meters; reading meters and calculating the units to be billed; investigating service irregularities and customers' complaints; operating the meter shop; operating laboratories for standardizing purposes or the testing of materials. Variations in functions and even in name may occur, depending largely on the organization of the company with which the meter department is connected and the lines along which the organization has been developed.

The functions of the meter department involve considerable detail, much of which is handled directly with the customer. The ability to handle these details and the experiences gained in dealing with customers result in many instances in other responsibilities being placed on the meter department, or in other related functions being grouped in or around its organization. These additional functions in some cases include wiring inspection; the running of service drops; the design, construction and maintenance in connection with the company's service performed on customers' premises; and the testing of utilization equipment. These items are enumerated since they indicate the channels of development open to metermen. As the company develops, careful consideration will usually result in increasing the responsibilities of the meter department.

The necessity for accuracy in all of the operations connected with metering has led to the development of standardizing and testing laboratories under the jurisdiction of the meter department. The laboratories of some companies are completely equipped in the field of electrical, steam, chemical, and mechanical testing and research.

ORGANIZATION

In developing a meter department the fundamentals of good organization must be observed, and efficient supervision provided. The head of the meter department should have a recognized assistant capable of being developed as the head of the department. It will be found desirable to separate the functions into groups and to have a designated supervisor in charge of each group, in order that the responsibilities for the various functions of the meter department may be fixed, and a foundation be established for future development.

PUBLIC RELATIONS

All meter department employees must convince themselves, other company employees, and the public of the important fact that all operations are performed in an ethical manner and with sincerity and accuracy. Pride in equipment and knowledge of the many and various methods in use inspire the confidence of others. If errors are made in carrying out instructions, a prompt admission makes for an easy and equitable settlement with customers. It must be the aim of every employee of the meter department to maintain the good will and confidence of the public.

Meter department employees are responsible servants of the public and must be constantly aware of their duties as such. All service must be rendered with an attitude which invites commendation from all concerned. Keen interest in public welfare, and prompt and efficient performance of every service will assure success to the company and the best service to the customers.

Visits to customers' premises for readings, testing meters, or for other reasons afford opportunities for employees to convey the company's interest in customers' welfare. Courteous consideration of every request will cause customers to appreciate the efforts made by the company to render adequate service.

All employees should be thoroughly acquainted with the company's rules and recommendations. A complete knowledge of the company's rules for conduct, applied with good judgment, will enable the meterman to meet most situations. However, a customer's point of view must be respected and discretion used in applying rules. Visits to customers' premises should cause a minimum of inconvenience to the customers.

The principles which should govern a meterman in dealing with customers are courtesy, frankness, and brevity. Courtesy is the outward expression of good character and should be the constant practice of every meterman because it makes friends for the employee and his company. Its practice improves the individual in self-esteem and general deportment, usually prevents misunderstanding, expedites business relations, and refutes any suggestion of callousness or indifference. This principle should be applied on all occasions and under all circumstances.

In answering a customer's question, a simple straightforward reply giving as much detail as is necessary for clarity will tend to remove doubt and provide assurance that frankness is the intent. Evasion invites suspicion and should never be resorted to. However, results of tests may require a checking by the proper authority before information is given to the customer and, if necessary, he should be so advised. Diplomacy and tact in the use of unfamiliar terms are necessary. Promises should be avoided; assurance to customers that any request will be conveyed to the proper official will, in general, satisfy.

An employee upon entering a customer's premises should make his presence and business known, and should present his identification card, badge or other credentials when requested.

All contacts with customers should be businesslike and concise. All work done on customers' premises should be planned carefully and carried out promptly. Conversations between employees while on customers' premises should relate only to the work at hand and should not be argumentative.

It is the duty of every employee to report promptly any unusual conditions that may affect the company's system or the customers' service, which may be observed on customers' premises or on the company's lines.

EDUCATION

Knowledge of the fundamentals of electricity is essential to a meterman. The training of employees in this highly specialized branch of measurement is of major importance. University courses provide fundamental background, but do not necessarily supply the opportunity for the specialized training which is required of a meterman. Short courses for metermen conducted periodically by many universities have been very beneficial but, of necessity, are confined to a limited number of men and consist mainly of general lectures and discussions of operating problems. Correspondence courses are of material assistance but are usually so general as to provide little detail of instruments and measurements.

Company-conducted lectures and short courses to supplement experience and knowledge are successful aids in the training and development of metermen. The availability of textbooks and the presence of competent instructors make class work an accepted method of training.

Books on electrical theory and related subjects may be found in utility or public libraries, or may be purchased at reasonable cost. Every employee of a meter department should become thoroughly familiar with all phases of meter work and obtain such additional knowledge of electrical engineering, and the utility business in general, as his opportunities provide.

Rapid developments in the art of metering make it necessary for every meterman to have access to current data, and to review regularly changes in practice due to the growth of the industry. Changes in design and appearance of metering equipment make it necessary for meter readers, installers, testers, and inspectors to be kept informed.

Practical experience combined with technical information obtained through the available mediums, all under the direction of competent supervision, will provide the required training for meter work.

SAFETY

Accidents to persons and property can be prevented. This can be accomplished by the proper observance of rules, reporting hazardous conditions to the proper authority, and the application of judgment. The importance of working safely cannot be over-emphasized.

SECTION 2

TERMS AND DEFINITIONS

A

Accuracy of a Meter—See **Percentage Registration.**

Active Component of Current—The active component of current in a single-phase two wire circuit is that component equal to the average power divided by the voltage. It is commonly referred to as the "In-phase component of the current," i.e. in phase with the voltage.

Active Component of Voltage—The active component of voltage in a single-phase two wire circuit is that component equal to the average power divided by the current. It is commonly referred to as the "In-phase component of voltage," i.e. in phase with the current.

Active Power—See **Power, Active.**

Admittance—Admittance is the reciprocal of the impedance.

Alternating Current—An alternating current is a periodic current which has alternately positive and negative values.

Ambient Temperature—Ambient temperature is the temperature of the surrounding medium, such as gas or liquid, which comes into contact with the parts of the apparatus.

Ammeter—An ammeter is an instrument for measuring the magnitude of an electric current. An ammeter is provided with a scale, usually graduated in amperes. If the scale is graduated in milliamperes or microamperes, the instrument is usually designated as a milliammeter or a microammeter.

Ampere—An ampere is the practical unit of electric current. It is the quantity of current caused to flow by a difference of potential of one volt through a resistance of one ohm.

Ampere-Hour—The ampere-hour is the quantity of electricity passing in one hour through a circuit in which the steady, or effective, value of the current is one ampere.

Ampere-Turn—Ampere-turn is a unit of magnetomotive force equal to that produced by one ampere flowing around a single turn of wire.

Angle of Lag—The angle of lag of one sinusoidal quantity with respect to a second sinusoidal quantity of the same period is the angular phase displacement of the first quantity behind the second quantity.

Angle of Lead—The angle of lead of one sinusoidal quantity with respect to a second sinusoidal quantity of the same period is the angular phase displacement of the first quantity ahead of the second quantity.

Aperiodic Instrument—An aperiodic instrument is an instrument whose pointer comes to rest without any oscillation. A dead-beat instrument.

Apparent Power—See **Power, Apparent.**

Artificial Load—See **Load, Artificial.**

Astatic—Astatic denotes little or no tendency to take a fixed or definite position or direction. As applied to integrating meters, this term denotes a form of construction securing independence of uniform stray magnetic fields, either by the use of two similar magnetic systems of opposite polarity, or by an equivalent construction using a single system.

Autotransformer—An autotransformer is a transformer in which part of the winding is common to both the primary and the secondary circuits.

B

Balanced Circuit—A balanced circuit is a circuit in which there are substantially equal currents, either alternating or direct, in all main or phase wires and substantially equal voltages between main or phase wires and between each main or phase wire and neutral (if one exists).

Balanced Polyphase Load—A balanced polyphase load is a load to which symmetrical currents are supplied when it is connected to a system having symmetrical voltages.

Note: The term balanced polyphase load is applied also to a load to which are supplied two currents having the same wave form and rms value and differing in phase by 90 electrical degrees when it is connected to a two phase (or quarter phase) system having voltages of the same wave form and rms value.

Balanced Polyphase System—A balanced polyphase system is a polyphase system in which both the currents and voltages are symmetrical.

Note: The term balanced polyphase system is applied also to a two phase (or quarter phase) system in which the voltages have the same wave form and rms value and differ in phase by 90 electrical degrees and in which the currents have the same wave form and rms value and differ in phase by 90 electrical degrees.

Bridge Circuit—A bridge circuit is a network which is so arranged that, when an electromotive force is present in one branch, the response of a suitable detecting device in another branch may be made zero by a suitable adjustment of the electrical constants of still other branches; and which is characterized by the fact that if the electromotive force and the detecting device are interchanged, after completing an adjustment, the response of the detecting device is still zero.

Burden—See **Transformer, Instrument Transformer Secondary Burden.**

C

Capacitance — Capacitance is that property of a system of conductors and dielectrics which permits the storage of electricity when potential differences exist between the conductors. Its value is expressed as the ratio of a quantity of electricity to a potential difference.

A capacitance value is always positive.

Capacitive Load—A capacitive load is a reactive load in which the current leads the voltage across the load.

Capacitive Reactance — Capacitive reactance is reactance due to capacitance.

Capacitor (Condenser)—A capacitor is a device, the primary purpose of which is to introduce capacitance into an electric circuit.

Cell, Standard—A standard cell is a cell which serves as a standard of electromotive force.

Centi—Centi is a prefix meaning one hundredth part of a specified unit (Centimeter).

Circuit, Electric—An electric circuit is a conducting part or a group of interconnected conducting parts capable of carrying electric current. Normally, it is the path or paths through which electric currents are intended to flow.

Circuit, Magnetic—A magnetic circuit is a closed path of magnetic flux, the path having the direction of the magnetic induction at every point.

Circuit, Parallel (Multiple) — A parallel circuit is a circuit consisting of two or more branch circuits connected to common terminal junction points.

Circuit, Parallel-Series—A parallel-series circuit is a parallel circuit in which two or more series circuits are connected in parallel.

Circuit, Polyphase — A polyphase circuit is a group of associated current paths (usually interconnected) which is energized, or which is intended to be energized, by a set of alternating electromotive forces, all of which have the same period but which differ in phase.

Circuit, Quarter-Phase — See **Circuit, Two-Phase.**

Circuit, Reactive—A reactive circuit is a circuit containing either inductance or capacitance, or both.

Circuit, Series—A series circuit is a circuit in which two or more devices are connected in series, i.e. so connected that the same current passes through each device.

Circuit, Series Parallel—A series parallel circuit is a series circuit in which two or more parallel circuits are connected in series.

Circuit, Shunt—A shunt circuit is a circuit for bypassing or shunting a portion of a current.

Circuit, Single-Phase — A single-phase circuit is either an alternating current circuit which has only two points of entry (terminals), or one which, having more than two points of entry, is intended to be so energized that the potential differences between all pairs of points of entry are either in phase or differ in phase by 180 degrees.

A single-phase circuit with only two points of entry is called a single-phase, two-wire circuit.

Circuit, Six-Phase—A six-phase circuit is a combination of circuits energized by alternating electromotive forces which differ in phase by one-sixth of a cycle; i.e. 60 degrees.

Note: In practice the phases may vary several degrees from the specified angle.

Circuit, Three-Phase — A three-phase circuit is a combination of circuits energized by alternating electromotive forces which differ in phase by one-third of a cycle; i.e. 120 degrees.

Note: In practice the phases may vary several degrees from the specified angle.

Circuit, Three-Phase Delta Connected—A three-phase, three-wire, delta connected circuit is a polyphase circuit in which a current path extends from the point of entry (terminal) of each line conductor to the points of entry of the other two line conductors. In a three-phase system, a delta connected circuit is often referred to as a mesh connected circuit.

Circuit, Three-Phase Wye Connected—A three-phase, four-wire, wye connected circuit is a polyphase circuit in which a current path extends from the point of entry (terminal) of each line conductor to a common conductor. The common conductor is referred to as the neutral conductor.

In a three-phase system, a wye connected circuit is often referred to as a star connected circuit.

Circuit, Two-Phase—A two-phase or quarter-phase circuit is a combination of circuits energized by alternating electromotive forces which differ in phase by a quarter of a cycle; i.e. 90 degrees.

Note: In practice the phases may vary several degrees from the specified angle.

Circuit, Two-Wire—A two-wire circuit is a metallic circuit formed by two adjacent conductors insulated from each other.

Circular Mil—A circular mil is the area of a circle whose diameter is one mil (1/1000 in.). A unit of area equal to $\frac{\pi}{4}$ (=0.7854) of a square mil. The area of a circle in circular mils is, therefore, equal to the square of its diameter in mils.

Clockwise Motion—Clockwise motion is rotation in the same direction as that of the hands of a clock, front view.

Commutator—A commutator is a cylindrical ring or disk assembly of conducting members, individually insulated, in a supporting structure with an exposed surface for contact with current collecting brushes and ready for mounting on an armature shaft, quill or spider.

Commutator Segments (Bars) — Commutator segments are the metal current-carrying members of a commutator which make contact with the brushes.

Component—A component is one of two or more forces which taken together would produce the same effect as a given force. The forces may be mechanical or electrical. One of two or more currents, voltages or fluxes which taken together would produce the same effect as a given current, voltage or flux.

Condenser—See **Capacitor.**

Conductance — Conductance is the property of an electric circuit, or of a body that may be used as a part of an electric circuit, which determines for a given electromotive force in the circuit or for a given potential difference between the terminals of a part of a circuit, the rate at which electrical energy is converted into heat or radiant energy, and which has a value such that the product of the conductance and the square of the electromotive force, or potential difference, gives the rate of conversion of energy.

In the general case, conductance is a function of the potential difference, but the term is most generally used in connection with circuits where the conductance is independent of the potential difference. Direct-current conductance is the reciprocal of direct-current resistance.

Conductivity—The conductivity of a material is the direct-current conductance between the opposite, parallel faces of a portion of the material having unit length and unit cross-section.

Connected Load — The connected load on a system, or part of a sytem, is the sum of the continuous ratings of the load consuming apparatus connected to the system, or part of the system, under consideration.

Consequent Pole — A consequent pole is a magnetic pole developed at some point of a magnet other than its extremities. In the plural, this term is used to designate adjacent poles of like polarity.

Constant—A constant is a quantity used in an equation, the value of which remains the same, regardless of the values of other quantities used in the equation.

Constant of an Electrical Instrument—The constant of an electrical instrument is that quantity which, applied as a factor to the indication of the instrument, converts the result into the desired unit.

Constant, Kilovar, of a Demand Meter—The kilovar constant of a demand meter is the multiplier used to convert the indicated, registered, or recorded demand reading to kilovars.

Constant, Kilovolt-Ampere, of a Demand Meter—The kilovolt-ampere constant of a demand meter is the multiplier used to convert the indicated, registered or recorded demand reading to kilovolt-amperes.

Constant, Kilowatt, of a Demand Meter—The kilowatt constant of a demand meter is the multiplier used to convert the indicated, registered or recorded demand to kilowatts.

Constant, Kilowatthour, of a Meter (Register Constant, Dial Constant)—The kilowatthour constant of a watthour meter is the multiplier used to convert the register reading to kilowatthours.

Constant, Watthour, of a Meter—The watthour constant of a watthour meter is the registration of one revolution of the rotating element expressed in watthours.

Constant, Wattsecond, of a Meter—The wattsecond constant of a watthour meter is the registration of one revolution of the rotating element expressed in wattseconds.

Coulomb—A coulomb is the practical unit of the quantity of electricity. It is the quantity of electricity which passes any section of an electrical circuit in one second, when the current in the circuit is one ampere.

Counterclockwise Motion—Counterclockwise motion is rotation in a direction opposite to that of the hands of a clock, front view.

Counter Electromotive Force—The counter electromotive force of any system is the effective emf within the system which opposes the passage of current in a specified direction.

Creep—A meter creeps if, with the load wires disconnected and with test voltage applied to the voltage circuits of the meter, the rotating element (rotor) rotates continuously; however a meter in service is considered to creep when, with all load wires disconnected, the rotating element (rotor) makes one complete revolution in five minutes or less.

Crest Voltmeter—A crest voltmeter is a voltmeter depending for its indications upon the crest, or maximum value of the voltage applied to its terminals.

Current—Current is the rate at which electricity flows or passes through a circuit. The practical unit of current, the ampere, is equal to one coulomb per second.

Current, Alternating—See **Alternating Current.**

Current Circuit of a Meter—The current circuit of a meter is that winding of the meter which carries the current in one conductor of the circuit in which a given electrical quantity is to be registered, or a definite fraction of that current, or a current dependent upon it.

Current, Direct or Continuous—See **Direct Current.**

Current, Foucault—See **Eddy Currents.**

Current, Lagging or Leading—See **Angle of Lag, Angle of Lead.**

Current Transformer—See **Transformer, Current.**

Currents, Eddy — See **Eddy Currents.**

Curve-Drawing Instruments — See **Recording Instrument.**

Cycle—A cycle is the complete series of values of a periodic quantity which occur during a period.

D

Damping Magnet—See **Magnet, Retarding.**

Damping of an Instrument—Damping of an instrument is the term applied to its performance to denote the manner in which the pointer settles to its steady indication after a change in the value of the measured quantity. Two general classes of damped motion are distinguished as follows:

(a) *Periodic* in which the pointer oscillates about the final position before coming to rest.

(b) *Aperiodic* in which the pointer comes to rest without overshooting the rest position.

The point of change between periodic and aperiodic damping is called critical damping.

Note: An instrument is considered to be critically damped when the degree of overshoot does not exceed an amount equal to one-half the rated accuracy of the instrument.

D'Arsonval Galvanometer — See **Galvanometer.**

Deflection Potentiometer—See **Potentiometer.**

Degree, Electrical—See **Electrical Degree.**

Delta Connection — See **Circuit, Three-Phase Delta Connected.**

Demand—The demand of an installation or system is the load which is drawn from the source of supply at the receiving terminals averaged over a suitable and specified interval of time. Demand is expressed in kilowatts, kilovolt-amperes, amperes, kilovars or other suitable units.

Demand Constant—See **Constant (Kilovar, Kilovolt-Ampere, Kilowatt) of a Demand Meter.**

Demand Factor—The demand factor is the ratio of the maximum demand of a system, or part of a system, to the total connected load of the system or the part of the system under consideration.

Demand Interval—The demand interval is the length of the interval of time upon which the demand measurement is based.

Demand, Maximum—The maximum demand of an installation or system is the greatest of all the demands which have occurred during the specified period of time.

Demand Meter—A demand meter is a device which indicates or records the demand or maximum demand.

A demand meter measures a quantity which is composed of an electrical factor and a time factor. An electrical element, a timing element, and an element for indicating or recording demand are required for this purpose, and these elements may be separate from or structurally combined with one another.

Demand Meter — Contact-Making Clock—A contact-making clock is a device designed to momentarily close an electrical circuit to a demand meter at definite and consecutive intervals.

Demand Meter — Contact Mechanism—A contact mechanism is a device for attachment to an electricity meter or to a demand-totalizing relay for the purpose of providing electrical impulses for transmission to a demand meter or relay.

Demand Meter—Electrical Element—The electrical element of a demand meter is that portion, the action or effect of which, in response to the electrical quantity to be measured, gives a measurement of that quantity.

For example, the electrical element of certain demand meters is similar to the ordinary ammeter or wattmeter of the deflection type; in others it is a watthour meter or other integrating meter; and in still others it is a register which introduces a heating effect which is interpreted in terms of amperes or watts.

The electrical quantity may be measured in kilowatts, kilowatthours, kilovolt-amperes, kilovolt-ampere hours, amperes, ampere-hours, kilovars, kilovarhours, or other suitable units.

Demand Meter—Indicating or Recording Element—The indicating or recording element of a demand meter is that mechanism which indicates or records the measurement of the electrical quantity as related to the demand interval.

In the case of integrated-demand meters, this element may be operated directly by and be a component part of the electrical element, or may be structurally separate from the electrical element. The demand may be indicated or recorded in kilowatts, kilovolt-amperes, amperes, kilovars, or other suitable units.

This element may be of an indicating type, indicating by means of a pointer related to its position on a scale or by means of the cumulative reading of a number of dial or cyclometer indicators; of a graphic type, recording on a circular or strip chart; or of a printing type, recording on a tape.

It may record the demand for each demand interval or may indicate only the maximum demand.

Demand Meter — Integrated-Demand (Block Interval Demand Meter)—An integrated-demand meter is one which indicates or records the demand obtained through integration.

Demand Meter—Lagged-Demand—A lagged-demand meter is one in which the indication of the maximum demand is subject to a characteristic time lag.

Demand Meter—Timing Element—The timing element of a demand meter is that mechanism through which the time factor is introduced into the result. The principal function of the timing element of a demand meter is to measure the demand interval, but it has a subsidiary function, in the case of certain types of demand meters, to provide also a record of the time of day at which any demand has occurred.

A timing element consists either of a clock or its equivalent, or of a lagging device which delays the indications of the electrical element. In the case of a curve-drawing meter, the timing element merely provides a continuous record of time on a chart or graph.

Demand Register—A demand register is that part of the meter which registers the revolutions of the rotating element in terms of units of electrical energy (or other quantity) and which also indicates the demand or maximum demand.

Demand Totalizing Relay—A demand totalizing relay is a device designed to receive and totalize electrical impulses from two or more sources for transmission to a demand meter or to another demand totalizing relay.

Dial Constant—See **Constant, Kilowatthour, of a Meter.**

Dial—First Dial of a Meter—The first dial of a meter is the graduated circle over which the most rapidly moving dial pointer moves. The test dial or dials, if any, are not considered.

Dial of a Meter—A dial of a meter is a graduated circle over which a dial pointer moves.

Dial Pointer of a Meter—A dial pointer of a meter is that part of the register which moves over the dial and points to the numbers on the divisions of the dial.

Dial Train of a Meter—A dial train of a meter comprises all the gear wheels and pinions used to interconnect the dial pointers.

Dielectric—A dielectric is a medium having the property that the energy required to establish an electric field is recoverable, in whole or in part, as electric energy.

> Note: The substance which separates the opposite coatings of a condenser is a dielectric. Dielectrics are non-conductors. All non-conductors or insulators are dielectrics. A vacuum is a dielectric.

Direct Current — Continuous Current—A direct current is a unidirectional current in which the changes in value under a steady load condition are either zero or so small that they may be neglected.

Disk Constant—See **Constant, Watthour, of a Meter.**

Diversity Factor—Diversity factor is the ratio of the sum of the maximum demands of the subdivisions of any system, or parts of a system, to the maximum demand of the whole system, or of the part of the system under consideration, measured at the point of supply.

Driving Element of a Meter (Stator)—A driving element (stator) of an induction watthour meter comprises a voltage circuit, one or more current circuits, and a combined magnetic circuit so arranged that their joint effect when energized is to exert a driving torque on the meter shaft by the reaction with currents induced in an individual, or a common, conducting disk.

In a "2-wire element" only one current circuit is present. In a "3-wire element" two current circuits of the same number of turns are wound on a common core.

E

Eddy Currents (Foucault Currents)—Eddy currents are those currents which are induced in the body of a conducting mass by a variation of magnetic flux.

> Note: The variation of magnetic flux may be the result of a varying magnetic field or of a relative motion of the mass with respect to the magnetic field.

Effective Resistance—Effective resistance is the resistance to a periodic current. Effective resistance is equal to watts divided by the square of the effective value of current.

Effective Value (Root-Mean-Square Value)—The effective value of a periodic quantity is the square root of the average of the squares of the instantaneous values of the quantity taken throughout one period. This value is also called the "root-mean-square" value, and is the value normally indicated by alternating current instruments.

Electrical Degree—An electrical degree is the 360th part of one complete alternating current cycle.

Electrical Energy — See **Energy, Electrical.**

Electric Potential—The electric potential of a point is the potential difference between the point and some equipotential surface, usually the surface of the earth, which is arbitrarily chosen as having zero potential. A point which has a higher potential than a zero surface is said to have a positive potential; one having a lower potential has a negative potential.

Electricity Meter — An electricity meter is a device that measures and registers the integral of an electrical quantity with respect to time.

The term "meter" is also used in a general sense to designate any type of measuring device, including all types of electric measuring instruments. Such use as a suffix or as part of a compound word (e.g. voltmeter, frequency meter) is universally accepted. "Meter" may be used alone with this wider meaning when the context is such as to prevent confusion with the narrower meaning here defined.

Electromagnet—An electromagnet is a magnet in which the magnetic field is produced by an electric current.

Electromotive Force—Electromotive force is the property of a physical device which tends to produce an electric current in a circuit.

Electrostatic Instrument—An electrostatic instrument is an instrument which depends for its operation on the forces of attraction and/or repulsion between bodies charged with electricity.

Electrostatic Potential—See **Electric Potential.**

Electrostatic Voltmeter—An electrostatic voltmeter is an electrostatic instrument provided with a scale, usually graduated in volts or kilovolts.

Electrothermic Instrument — An electrothermic instrument is an instrument which depends for its operation on the heating effect of a current. Two distinct types are (a) the expansion type, including the "hot-wire" and "hot-strip" instruments, and (b) the thermocouple type.

Element of a Meter—See **Driving Element of a Meter.**

Energy, Electrical—Electrical energy is the summation of instantaneous electrical power over a period of time, or it is the average electrical power over a period of time multiplied by the time.

F

Farad—The farad is the practical unit of capacitance. It is the capacitance of a capacitator in which a charge of one coulomb produces a potential difference between the terminals of one volt.

Field Coil—A field coil is a suitably insulated winding to be mounted on a field pole to magnetize it.

Field, Magnetic—A magnetic field is a region of magnetic influence surrounding a magnet or a conductor carrying electric current.

Field, Rotating Magnetic—A rotating magnetic field is a magnetic field in which a set of magnetic poles is produced, whose successive positions are such that rotation or continual progression of the field is effected.

Field, Stray—A stray field is usually a disturbing magnetic field produced by sources external or foreign to any given apparatus.

Foucault Currents—See **Eddy Currents.**

G

Galvanometer—A galvanometer is an instrument for indicating or measuring a small electric current, or a function of the current, by means of a mechanical motion derived from electromagnetic or electrodynamic forces which are set up as a result of the current.

Gauss—The gauss is a unit of magnetic flux density.

Gear Ratio—The gear ratio is the number of revolutions of the rotating element of a meter for one revolution of the first dial pointer.

Gilbert—The gilbert is a unit of magnetomotive force.

Gradient—A gradient is the rate of change (increase or decrease) of voltage or other quantity with respect to distance.

Gram—The gram is a unit of mass in the metric system.

Graphic Instrument—See **Recording Instrument.**

Ground—A ground is a conducting connection, whether intentional or accidental, between an electric circuit or equipment and earth, or to some conducting body which serves in place of the earth.

Ground Return Circuit—A ground return circuit is a circuit in which the earth is utilized to complete the circuit.

Grounding Conductor—A grounding conductor is a conductor used to connect an equipment, device or wiring system with a grounding electrode or electrodes.

Grounding Electrode—A grounding electrode is a conductor imbedded in the earth, used for maintaining ground potential on conductors connected to it and for dissipating into the earth current conducted to it.

H

Hecto—Hecto is a prefix meaning one hundred of a specified unit (hectowatt).

Henry—The henry is the practical unit of inductance. An inductance of one henry produces an electromotive force of one volt when the current is changing at the rate of one ampere per second.

Horological Standards—Horological standards are standards for the measurement of time.

Horsepower—The horsepower is a commercial unit of power equal to the average rate of doing work when 33,000 pounds is raised one foot in one minute. A horsepower is practically equal to 746 watts.

Horsepower-Hour—The horsepower-hour is a unit of energy equal to the work done by one horsepower acting for one hour.

Hot-Wire Instrument — A "hot-wire" instrument is an electrothermic instrument which depends for its operation on the expansion by heat of a wire carrying a current. The "hot-strip" instrument differs from the hot-wire instrument only in having a metallic strip in place of a wire.

Hysteresis Loop—A hysteresis loop for a magnetic material in a cyclicly magnetized condition is a curve (usually with rectangular coordinates) showing, for each value of the magnetizing force, two values of the magnetic induction; one when the magnetizing force is increasing, the other when it is decreasing.

Hysteresis Loss—Magnetic hysteresis loss in a material for a specified cycle of magnetizing force is the energy converted into heat as a result of magnetic hysteresis when the magnetic induction is also cyclic.

Hysteresis, Magnetic — Magnetic hysteresis is the property of a magnetic material by virtue of which the magnetic induction for a given magnetizing force depends upon the previous conditions of magnetization.

Hysteretic Lag—Hysteretic lag is the angle between equivalent sine waves of a magnetizing current and the resulting magnetic flux in a magnetic circuit. This angle is caused by magnetic hysteresis.

I

Impedance—The impedance of a portion of an electric circuit to a completely specified periodic current and potential difference is the ratio of the effective value of the potential difference between the terminals to the effective value of the current, there being no source of power in the portion under consideration.

Induced Current—Induced current is the current produced in a closed circuit by changing the number of lines of magnetic force linking through the circuit.

Induced Electromotive Force—Induced electromotive force is electromotive force produced by electromagnetic or electrodynamic action.

Inductance — Inductance is the (scalar) property of an electric circuit, or two neighboring circuits, which determines the electromotive force induced in one of the circuits by a change of current in either of them.

Inductance, Mutual—Mutual inductance is the common property of two associated electric circuits which determines, for a given rate of change of current in one of the circuits, the electromotive force induced in the other.

Mutual inductance is the ratio of the electromotive force induced in a circuit to the rate of change of the inducing current in a magnetically associated circuit.

Inductance, Self—Self-inductance is the property of an electric circuit which determines, for a given rate of change of current in the circuit, the electromotive force induced in the same circuit.

Inductive—Having inductance, e.g. inductive circuit, inductive load. (Circuits containing iron or steel that is magnetized by the passage of current are highly inductive.)

Inductive Reactance—Inductive reactance is reactance due to inductance.

Inductor—An inductor is a device, the primary purpose of which is to introduce inductance into an electric circuit.

Instrument, Electrical—An electrical instrument is a device for measuring the present value of the quantity under observation. An instrument may be an indicating instrument or a recording instrument.

The term "instrument" is used in two different senses; (a) instrument proper and (b) to include not only the instrument proper but, in addition, any necessary auxiliary devices, such as shunts, shunt leads, resistors, reactors, capacitors or instrument transformers.

The term "meter" is also used in a general sense to designate any type of measuring device, including all types of electric measuring instruments. Such use as a suffix or as part of a compound word (e.g. voltmeter, frequency meter) is universally accepted. "Meter" may be used alone with this wider meaning when the context is such as to prevent confusion with the narrower meaning of "electricity meter."

Instrument Multiplier—An instrument multiplier is a particular type of series resistor or impedor which is used to extend the voltage range of a meter or instrument beyond some particular value for which the meter or instrument is already complete.

Instrument Transformer — See **Transformer, Instrument.**

Insulation Resistance—The insulation resistance of an insulated conductor is the resistance offered by its insulation, to an impressed d-c voltage tending to produce a leakage of current through the same.

J

Joule—The joule is the practical unit of electrical energy equal to a watt-second.

Joule's Law—The rate at which heat is produced in an electric circuit of constant resistance is proportional to the square of the current.

K

Kilo—Kilo is a prefix meaning one thousand of a specified unit, (kilovolt, kilowatt).

L

Lagging Current—A lagging current is an alternating current lagging the impressed electromotive force which produces it. See Angle of Lag.

Laminated Core—A laminated core is an iron core composed of sheets in planes parallel to its magnetic flux-paths, in order to minimize eddy currents.

Leading Current—A leading current is an alternating current which leads the electromotive force producing it. See Angle of Lead.

Lenz's Law—The current induced in a circuit as a result of its motion in a magnetic field is in such a direction as to exert a mechanical force opposing the motion.

Line-Drop Voltmeter Compensator—A line-drop voltmeter compensator is a device used in connection with a voltmeter which causes the latter to indicate the voltage at some distant point of the circuit.

Lines of Force—Lines of force are imaginary lines within a magnetic or electrostatic field which indicate by their direction the direction of magnetic or electrostatic force at each point. By convention it is considered that the number of such lines per unit area (taken at right angles to lines of force) is a measure of the strength of the field.

Lines of Magnetization—See **Lines of Force.**

Load, Artificial (Phantom Load)—An artificial load is a loading transformer used to provide a low voltage current for test purposes.

Load Factor—The load factor of an installation or system is the ratio of the average load to the maximum load during a certain period of time. The average load is taken over a certain period of time, such as a day, a month, or a year, and the maximum is taken as the average over a short interval of the maximum load within that period.

Loading Transformer — A loading transformer is a transformer of low secondary voltage, usually provided with means for obtaining various definite values of current, whereby the current circuit of the device under test and of the test standard can be energized.

M

Magnet—A magnet is a body which produces a magnetic field external to itself.

Magnet Coil—A magnet coil is a coil of insulated wire by which the magnetizing current is carried around the core of an electromagnet.

Magnet, Retarding (Braking, Drag, Damping)—A retarding magnet is a magnet employed for the purpose of limiting the speed of the rotating element of a meter or the moving element of an instrument.

Magnetic Circuit—See **Circuit, Magnetic.**

Magnetic Field—See **Field, Magnetic.**

Magnetic Flux—See **Lines of Force.**

Magnetic Permeability—See **Permeability, Normal.**

Magnetic Pole—The magnetic poles of a magnet are those portions of the magnet toward which the external magnetizing force tends to converge or diverge.

The size and position of the poles of a magnet depend upon its shape and characteristics. For a long thin magnet, the poles occupy small regions near the ends, so that for many purposes the poles of such a magnet may be considered as concentrated at points.

Magnetic Shield—A magnetic shield is a magnetic barrier placed about a device or portions of a device to weaken within the shielded area the magnetic influence of external magnetized bodies or of electric currents.

Magnetomotive Force — Magnetomotive force is the force which produces magnetic flux. In any path, the magnetomotive force resulting from a current is directly proportional to the current which links the path.

Marked Ratio of an Instrument Transformer—See **Transformer, Instrument Transformer Marked Ratio.**

Maximum Demand—See **Demand, Maximum.**

Mega—Mega is a prefix meaning one million of a specified unit (megawatt, megohm).

Meter—See **Electricity Meter.**

Meter, Ampere-Hour—An ampere-hour meter is an electricity meter which measures and registers the integral, with respect to time, of the current of the circuit in which it is connected. The unit in which this integral is measured is usually the ampere-hour.

Meter, Excess—An excess meter is a meter that records either exclusively or separately that portion of the energy consumption taken at a demand in excess of a predetermined demand.

Meter, Multirate—A multirate meter is a meter which registers at different rates or on different dials at different hours of the day.

Meter, Volt-Ampere-Hour—A volt-ampere-hour meter is an electricity meter which measures and registers the integral, with respect to time, of the apparent power in the circuit in which it is connected. The unit in which the integral is measured is usually the kilovolt-ampere-hour.

Meter, Varhour (Reactive Volt-Ampere-Hour Meter)—A varhour meter is an electricity meter which measures and registers the integral, with respect to time, of the reactive power of the circuit in which it is connected. The unit in which this integral is measured is usually the kilovarhour.

Meter, Watthour—A watthour meter is an electricity meter which measures and registers the integral, with respect to time, of the active power of the circuit in which it is connected. This power integral is the energy delivered to the circuit during the interval over which the integration extends, and the unit in which it is measured is usually the kilowatthour.

Mho—The mho is the practical unit of conductance. In a nonreactive circuit, the conductance in mhos is equal to the reciprocal of the resistance in ohms.

Micro—Micro is a prefix meaning one millionth part of a specified unit (microfarad, microhm).

Mil—The mil is a unit of length equal to one one-thousandth of an inch.

Milli—Milli is a prefix meaning one thousandth part of a specified unit (milliampere, millihenry, millivolt).

Multiple Circuit — See **Circuit, Parallel.**

Multiple-Series Circuit — See **Circuit, Parallel-Series.**

Mutual Inductance—See **Inductance, Mutual.**

N

Non-Reactive or Non-Inductive Load—A non-reactive or non-inductive load is a load in which the current is in phase with the voltage across the load. (The term non-inductive load is generally used for non-reactive load).

Null Method—A null method is any method employed in electrical measurement, in which the values of the electromotive force, the resistance, current or other similar quantities, are determined by balancing against them equal but known values of similar quantities and ascertaining the equality, not by the deflection of a galvanometer or electrometer, but by the absence of such deflections.

O

Ohm—The ohm is the practical unit of electrical resistance. It is the resistance which allows one ampere to flow when the impressed potential is one volt.

Ohm's Law—Ohm's law states that the current which flows in an electric circuit is directly proportional to the electromotive force in the circuit. Ohm's law does not apply to all circuits. It is applicable to all metallic circuits and to many circuits containing an electrolytic resistance.

Ohm's law was first enunciated for a circuit in which there is a constant electromotive force and an unvarying current. It is applicable to varying currents if account is taken of the induced electromotive force resulting from the self-inductance of the circuit and of the distribution of current in the cross-section of the circuit.

Oscillograph—An oscillograph is an instrument for producing a record of the instantaneous values of one or more rapidly varying electrical quantities as a function of time or of another electrical or mechanical quantity.

P

Parallel Circuit—See **Circuit, Parallel.**

Parallel-Series Circuit—See **Circuit, Parallel-Series.**

Percentage Error—The percentage error of a meter is the difference between its percentage registration and one hundred per cent (100%).

Percentage Registration—Percentage registration of a meter is the ratio of the actual registration of the meter to the true value of the quantity measured in a given time, expressed as a percentage. Percentage registration is also sometimes referred to as the accuracy or percentage accuracy of the meter.

Period—The period of an alternating current is the time required for the current to pass through one cycle.

Period of an Instrument—The period of an instrument, sometimes called the "periodic time," is the time between two consecutive swings of the pointer or indicating means in the same direction through the rest position.

Periodic Function—A periodic function is a function which repeats itself after a definite time, or period.

Permeability, Normal—Normal permeability is the ratio of the normal induction to the corresponding magnetic intensity.

Phantom Load—See **Load, Artificial.**

Phase Angle—The phase angle or phase difference between a sine voltage and a sine current is defined as the number of electrical degrees between the beginning of the cycle of voltage and the beginning of the cycle of current.

Phase Angle of a Current Transformer—The phase angle of a current transformer is the angle between the primary current vector and the secondary current vector reversed. This angle is conveniently considered as positive when the reversed secondary current vector leads the primary current vector. It is preferably designated by the symbol β.

Phase Angle of a Potential Transformer—The phase angle of a potential transformer is the angle between the primary voltage vector and the secondary voltage vector reversed. This angle is conveniently considered as positive when the reversed secondary voltage vector leads the primary voltage vector. It is preferably designated by the symbol γ.

Phase Difference, Lead and Lag—See **Angle of Lag, Angle of Lead.**

Phase, Quarter, or Two-Phase—See **Circuit, Two-Phase.**

Phase Sequence—Phase sequence is the order in which the instantaneous values of the voltages or currents of a polyphase system reach their maximum positive values.

Phase Shifter—A phase shifter is an adjustable device for creating differences in phase angle between current and electromotive forces, or between electromotive forces.

Phase, Single—See **Circuit, Single-Phase.**

Phase, Six—See **Circuit, Six-Phase.**

Phase, Split—A split phase is a difference produced between the phases of two or more alternating currents into which a single-phase alternating current has been divided.

Phase, Three—See **Circuit, Three-Phase.**

Phase, Two—See **Circuit, Two-Phase.**

Polarity—The polarity of a battery or transformer is the designation of the direction in which instantaneous current tends to flow. As applied to instrument transformers, instantaneous current flowing into the marked (polarity) primary lead, induces current flowing instantaneously out of the marked (polarity) secondary lead.

Polyphase Circuit — See **Circuit, Polyphase.**

Portable Standard Watthour Meter—A portable standard watthour meter is a portable form of watthour meter principally used as a standard for testing other watthour meters. It is usually provided with several current and voltage ranges and with dials indicating revolutions and fractions of a revolution of the rotating element.

Potential Difference—The electric potential difference between two points is measured by the work required to transfer a unit quantity of positive electricity from the point of lower potential to the point of higher potential.

Potential, Electric—See **Electric Potential.**

Potential Transformer—See **Transformer, Potential.**

Potentiometer—A potentiometer is an instrument for measuring small potential differences.

Power—Power is the rate at which energy is transferred or transformed.

Power, Active—Single-Phase Circuit—Active power at the points of entry (terminals) of a single-phase, two-wire circuit is the time average of the values of the instantaneous power when the average is taken over a cycle of the alternating current.

The value of active power is given in watts when the effective current is in amperes and the effective potential difference is in volts.

Power, Apparent — Single-Phase Circuit—Apparent power at the two points of entry (terminals) of a single-phase two-wire circuit is equal to the product of the effective current in one conductor multiplied by the effective potential difference between the two points of entry.

Note: The term volt-ampere, without a qualifying adjective, is used as the unit of apparent power because it can be directly measured by means of a voltmeter and an ammeter. Also, it has historical significance.

Power Factor—Power factor is the ratio of active power to apparent power. This power factor of a single-phase circuit in which a sine voltage causes a sine current to flow is equal to the cosine of the phase angle between the voltage and the current.

Power, Reactive — The reactive power at the two points of entry (terminals) of a single-phase, two-wire circuit is, for the special case of a sinusoidal current and a sinusoidal potential difference of the same frequency, equal to the product obtained by multiplying the effective value of the current by the effective value of the potential difference and by the sine of the angular phase difference by which the current leads or lags the potential difference; and is for the more general case of a periodic current and a periodic potential difference of the same fundamental frequency, the algebraic sum of the reactive powers corresponding to the sinusoidal harmonic components.

The value of reactive power is given in vars when the effective current is in amperes and the effective potential difference is in volts.

Primary Winding of a Transformer—The primary winding of a transformer is the winding on the input side.

Pulsating Current—A pulsating current is a periodic current the values of which are always positive (or always negative).

Q

Quadrature — Quadrature expresses the phase relationship between two periodic quantities of the same period when the phase difference between them is one fourth of a period, 90 electrical degrees.

Quarter-Phase Circuit—See **Circuit, Two-Phase.**

R

Rating—A rating of a machine, apparatus or device is a designated limit of operating characteristics based on definite conditions.

Note: Such operating characteristics as load, voltage, frequency, etc., may be given in the rating.

Reactance—The reactance of a portion of a circuit for a sinusoidal current and potential difference of the same frequency is the product of the sine of the angular phase difference between the current and potential difference times the ratio of the effective potential difference to the effective current, there being no source of power in the portion of the circuit under consideration.

Reactance Coil—See **Reactor.**

Reactive Circuit—See **Circuit, Reactive.**

Reactive Component—The reactive component of current, voltage, power or energy is the square root of the difference between the square of the total quantity and the square of the active component of the quantity.

Reactive Factor—The reactive factor is the ratio of reactive power to apparent power.

Reactive Load—A reactive load is a load in which the current is not in phase with the voltage across the load.

Reactive Volt-Ampere-Hour Meter—See **Meter, Varhour.**

Reactor—A reactor is a device used for introducing reactance into a circuit for purposes such as motor starting, paralleling transformers and control of current.

Recording Instrument (Graphic Instrument)—A recording instrument is an instrument which makes a graphic record of the value of an electrical quantity as a function of another variable, usually time. The term "recording instrument" may be replaced by the shorter term "recorder."

Rectifier — A rectifier is a device which converts alternating current into unidirectional current by virtue of a characteristic permitting appreciable flow of current in only one direction.

Register—The register is that part of the meter which registers the revolutions of the rotating element in terms of units of electric energy (or other quantity).

Register Constant—See **Constant, Kilowatthour, of a Meter.**

Register Ratio—The register ratio is the number of revolutions of the gear meshing with the worm or pinion on the rotating element for one revolution of the first dial pointer.

Register Reading—A register reading is the numerical value indicated on the dials by the dial pointers. Neither the register constant nor the test dial (or dials), if any exist, is considered.

Register, Two Rate—A two rate register is a register having two sets of dials with a changeover gear arrangement such that integration of the electrical quantity will be registered on one set of dials for a specified number of hours each day and on the other set of dials during the remaining hours.

Register, Universal — A universal register is a register of specific ratio used in conjunction with all ratings of any type of integrating meter designed to accommodate it. The register constant of a universal register is proportional to the rating of the meter on which it is mounted.

Registration—The registration of a meter is equal to the product of the register reading and the register constant. The registration during a given period of time is equal to the product of the register constant and the difference between the register readings at the beginning and the end of the period.

Reluctance—Reluctance is the reciprocal of permeance.

Reluctivity—Reluctivity of a medium is the reciprocal of its permeability.

Residual Magnetism (Remanence)—Remanence is the magnetic induction which remains in a magnetic circuit after the removal of an applied magnetomotive force.

Resistance—Resistance is the opposition offered by a substance or body to the passage through it of an electric current which converts electric energy into heat. Resistance is the reciprocal of conductance.

Resistivity—The resistivity of a material is the reciprocal of its conductivity. The resistance expressed in ohms between two opposite faces of a centimeter cube of material, and usually coupled with a statement of the temperature.

Resistor—A resistor is a device, the primary purpose of which is to introduce resistance into an electric circuit.

Rheostat—A rheostat is an adjustable resistor so constructed that its resistance may be changed without opening the circuit in which it may be connected.

Root-Mean-Square — See **Effective Value.**

Rotating Element of a Meter (Rotor)—The rotating element (rotor) of an electricity meter is that part of the meter which is directly driven by electromagnetic action.

Rotating Magnetic Field — See **Field, Rotating Magnetic.**

Rotating Standard—See **Portable Standard Watthour Meter.**

Rotor—See **Rotating Element of a Meter.**

S

Scalar Quantity—A scalar quantity is any quantity which has magnitude only. The relationship between any physical quantity and the unit used to measure it is completely described by a real number.

Examples of scalar quantities for which the relationship to the unit can be represented by a positive number: Mass, energy, electric resistance.

Examples of scalar quantities for which the relationship can be represented by either a positive or a negative number: Time, temperature, quantity of electricity.

Secondary Winding—The secondary winding of a transformer is the winding on the output side which receives power from the primary winding by induction.

Self-Induction — See **Inductance, Self.**

Series Circuit—See **Circuit, Series.**

Series-Parallel Circuit—See **Circuit, Series-Parallel.**

Shaft Reduction (Spindle Reduction, First Reduction)—The shaft reduction of a meter is the gear reduction between the shaft, or spindle, of the rotating element and the first gear of the register.

Shield, Magnetic — See **Magnetic Shield.**

Shunt, Instrument—An instrument shunt is a particular type of resistor designed to be connected in parallel with a circuit of an instrument to extend its current range. The shunt may be internal or external to the instrument proper.

Shunt Leads—Shunt leads are leads which connect a circuit of an instrument to the shunt. The resistance of these leads is taken into account in the adjustment of the instrument.

Shunt Ratio—Shunt ratio as applied to shunted type meters and instruments is the ratio of the current being measured to the current in the meter or instrument.

Single-Phase—See **Circuit, Single-Phase.**

Sinusoidal Current (Sine Wave)—A simple sinusoidal current is a symmetrical alternating current, the instantaneous values of which are equal to the products of a constant and the sine or cosine of an angle having values varying linearly with time.

Six-Phase Circuit—See **Circuit, Six-Phase.**

Slide Wire Bridge—A slide wire bridge is a resistance measuring bridge, having one or more arms formed of a single conductor upon which runs a sliding contact.

Solenoid—A solenoid is an electromagnet having an energizing coil approximately cylindrical in form and operating on a movable core or plunger.

Specific Resistance—See **Resistivity.**

Split-Phase—See **Phase, Split.**

Standard Cell—See **Cell, Standard.**

Star Connection — See **Circuit, Three-Phase, Wye Connected.**

Static Condenser—See **Capacitor.**

Static Voltmeter—See **Electrostatic Voltmeter.**

Stator—See **Driving Element of a Meter.**

Step-Down Transformer — See **Transformer, Step-Down.**

Step-Up Transformer—See **Transformer, Step-Up.**

Stray Field—See **Field, Stray.**

Symmetrical Voltages and Currents—A symmetrical alternating current or voltage is an alternating current or voltage, all values of which separated by a half period have the same magnitude but opposite sign.

Polyphase voltages or currents are symmetrical when the voltages or currents have the same wave shape and root-mean-square value and differ in phase each from the next by the same angle.

Synchronism — Synchronism expresses the phase relationship between two or more periodic quantities of the same period when the phase difference between them is zero.

Synchroscope — A synchroscope is an instrument for indicating whether two periodic quantities are synchronous. It embodies a continuously rotatable element, the position of which at any time is a measure of the instantaneous phase difference between the quantities, while its speed of rotation indicates the frequency difference between the quantities, and its direction of rotation indicates which of the quantities is of higher frequency.

T

Thermocouple—A thermocouple is a pair of dissimilar conductors so joined that an electromotive force is developed by the thermoelectric effect when the two junctions are at different temperatures.

Thermoelectric Effect (Seebeck Effect)—A thermoelectric effect is one in which an electromotive force results from a difference of temperature between two junctions of dissimilar metals in the same circuit.

Thermoelectric Laws—(1) the thermoelectromotive force is, for the same pair of metals, proportional through a considerable range of temperature to the excess of temperature of the junction over the rest of the circuit.

(2) The total thermoelectromotive force in a circuit is the algebraic sum of all the separate thermoelectromotive forces at the various junctions.

Three-Phase Circuit—See **Circuit, Three-Phase.**

Three-Wire System—A three-wire system (d-c or single-phase a-c) is a system of electric supply comprising three conductors, one of which (known as the "neutral wire") is maintained at a potential midway between the potential of the other two (referred to as the outer conductors).

> Note: Part of the load may be connected directly between the outer conductors, the remainder being divided as evenly as possible into two parts each of which is connected between the neutral and one outer conductor.

Torque of an Instrument — The torque of an instrument is the turning moment produced by the electrical quantity to be measured, acting through the mechanism.

Transformer—A transformer is an electrical device, without continuously moving parts which by electromagnetic induction transforms electric energy from one or more circuits to one or more other circuits at the same frequency, usually with changed values of voltage and current.

Transformer, Current — A current transformer is a transformer, intended for measurement or control purposes, designed to have its primary winding connected in series with a circuit carrying the current to be measured or controlled.

Transformer, Instrument—An instrument transformer is a transformer in which the conditions of current or voltage and of phase position in the primary circuit are represented with acceptable accuracy in the secondary circuit. Instrument transformers are classified according to their accuracy under specified conditions. An instrument transformer may be either an instrument current transformer or an instrument potential (voltage) transformer.

Transformer, Instrument Transformer Correction Factor—The instrument transformer correction factor is the factor by which the reading of a wattmeter or watthour meter must be multiplied to correct for the combined effect of the instrument transformer ratio correction factor and the instrument transformer phase angle correction factor.

Transformer, Instrument Transformer Marked Ratio—The marked ratio of a current or a potential instrument transformer is the ratio of the primary current or voltage, as the case may be, to the secondary current or voltage, as given on the rating plate.

Transformer, Instrument Transformer Phase Angle Correction Factor—The instrument transformer phase angle correction factor is that factor by which the reading of a wattmeter or watthour meter, operated from the secondary of a current or a potential transformer or both, must be multiplied to correct for the effect of phase displacement of current and voltage due to the measuring apparatus.

This factor equals the ratio of the true power factor to the apparent power factor.

Transformer, Instrument Transformer Ratio Correction Factor—The ratio correction factor is that factor by which the marked ratio of a current or a potential transformer must be multiplied to obtain the true ratio.

This factor is expressed as the ratio of true ratio to marked ratio. If both a current transformer and a potential transformer are used in conjunction with a wattmeter or watthour meter, the combined ratio correction factor is the product of the individual ratio correction factors.

Transformer, Instrument Transformer Secondary Burden—The burden of an instrument transformer is that property of the circuit connected to its secondary which determines the active and reactive power at its secondary terminals. It is expressed either as total ohms impedance, together with the effective resistance and reactance components of the impedance, or as the total volt-amperes and power factor of the secondary devices and leads.

The values expressing the burden apply to the condition of rated secondary current or voltage of the instrument transformer and a stated frequency, both of which must also be included with the burden expression.

The impedance expression is more applicable to current transformers, the volt-ampere power factor expression to potential (voltage) transformers.

Transformer, Instrument Transformer True Ratio—The true ratio of a current or a potential instrument transformer is the ratio of rms primary current or voltage, as the case may be, to the rms secondary current or voltage under specified conditions.

Transformer, Phase Shifting—A phase shifting transformer is a transformer in which the secondary voltage may be adjusted to have any desired phase relation with the primary voltage by mechanically orienting the secondary winding with respect to the primary. The primary winding of such a transformer usually consists of a distributed symmetrical polyphase winding and is energized from a polyphase circuit.

Transformer, Phasing—A phasing transformer is an autotransformer intended to be connected across the phases of a polyphase circuit so as to provide voltages in the proper phase relations for energizing varmeters, varhourmeters, or other measurement equipment.

Transformer, Potential—A potential (voltage) transformer is a transformer, intended for measurement or control purposes, which is designed to have its primary winding connected in parallel with a circuit, the voltage of which is to be measured or controlled.

Transformer, Step-Down—A step-down transformer is a transformer in which the energy transfer is from a high voltage winding to a low voltage winding or windings.

Transformer, Step-Up—A step-up transformer is a transformer in which the energy transfer is from a low voltage winding or windings to a high voltage winding or windings.

Two-Phase Circuit—See **Circuit, Two-Phase.**

Two-Wire Circuit — See **Circuit, Two-Wire.**

Two-Wire System—A two-wire system (d-c or single-phase a-c) is a system of electric supply comprising two conductors between which the load is connected.

V

Var—The var is the unit of reactive power. The reactive power in a circuit carrying an effective sinusoidal current of one ampere in quadrature with an effective sinusoidal potential difference of one volt is one var.

Varhour—The varhour is the unit for expressing the integral of reactive power in vars over an interval of time expressed in hours.

Varhour Meter—See **Meter, Varhour.**

Vector Quantity—A vector quantity is a quantity which has both magnitude and direction. The most common method of describing a vector quantity is by means of the projection on a system of rectangular coordinates.

Vector Diagram—A vector diagram is a diagram representing the relations of vector quantities.

Vector Sum—Vector sum is the geometrical sum of two or more vector quantities.

Volt—The volt is the practical unit of electromotive force. One volt will produce a current of one ampere through a resistance of one ohm.

Voltage (Of a Circuit)—Voltage is the greatest effective difference of potential between any two conductors of the circuit concerned.

Voltage Circuit of a Meter—The voltage circuit of a meter is that winding of the meter to which is applied the voltage between two conductors of the circuit in which a given electrical quantity is to be registered, or a definite fraction of that voltage, or a voltage dependent upon it.

Voltage Transformer—See **Transformer, Potential.**

Volt-Ampere—The volt-ampere is the practical unit of apparent power. It is the apparent power when one ampere flows between two points having a potential difference of one volt.

Volt-Ampere-Hour—A volt-ampere-hour is the unit for expressing the integral of apparent power in volt-amperes over an interval of time expressed in hours.

Volt-Ampere-Hour Meter—See **Meter, Volt-Ampere-Hour.**

Voltage Divider—A voltage divider is a combination of two or more resistors, capacitors, or other circuit elements so arranged in series that the voltage across one of them is a definite and known fraction of the voltage applied to the combination, provided the current drain at the tap point is negligible or taken into account.

A voltage divider may be used as an instrument multiplier. The term "volt box" is usually limited to resistance voltage dividers intended to extend the range of d-c potentiometers.

Voltmeter—A voltmeter is an instrument for measuring the magnitude of electric potential difference. A voltmeter is provided with a scale, usually graduated in either volts, millivolts, or kilovolts. If the scale is graduated in millivolts or kilovolts the instrument is usually designated as a millivoltmeter or a kilovoltmeter.

W

Watt—The watt is the practical unit of active power and is defined as the rate at which energy is delivered to a circuit. It is the power expended when a current of one ampere flows through a resistance of one ohm.

Watthour—A watthour is the practical unit of electrical energy which is expended or transformed in one hour when the power is one watt.

Watthour Constant—See **Constant, Watthour, of a Meter.**

Watthour Meter—See **Meter, Watthour.**

Wattless Component of Current or Wattless Current—See **Reactive Component.**

Wattmeter—A wattmeter is an instrument for measuring the magnitude of the active power in an electric circuit. A wattmeter is provided with a scale, usually graduated in either watts, kilowatts, or megawatts.

Wattsecond Constant—See **Constant, Wattsecond, of a Meter.**

Wave Form or Shape—The wave form of an alternating voltage or current is the shape of a curve plotted to represent the variation of the voltage or current with respect to time. The sine wave form is the standard of reference. When the wave forms of the voltage and the current are not the same, the power factor of the circuit will be less than unity, even when the voltage and the current reverse at the same instant.

Wheatstone Bridge—A Wheatstone bridge is a device for measuring electrical resistance (d-c). See **Bridge Circuit**

Z

Zero Method—See **Null Method**

Zero Potential—Zero potential is an arbitrary potential level from which electric levels are measured. The earth's potential.

SECTION 3

METHODS OF MEASUREMENT AND PRINCIPLES OF METERS

MEASUREMENT OF POWER

Power is the rate of utilization of energy. The basic unit of mechanical power, according to the English system, is the foot-pound per minute, which is the power applied when one pound is raised one foot in one minute at a uniform speed. This unit is small and for practical work the horsepower, equal to 33,000 foot-pounds per minute, is commonly used. The basic unit of electrical power is the watt, which is the power developed in a circuit where an unvarying current of one ampere is caused to flow by a potential difference of one volt. One horsepower is equal to 746 watts, and one kilowatt is equal to 1000 watts. Power should not be confused with energy, which is the summation of power over a period of time; in other words, energy is the product of power and time and, for hourly periods, is expressed as horsepower-hours, watthours, kilowatthours, etc.

In an electrical circuit the power at any instant is the product of the current in the circuit and the voltage applied to the circuit. Ordinarily one is not concerned with an instantaneous value of power, but a value averaged over a period of time. For direct current, power may be calculated as the product of the current in the circuit as measured with an ammeter, and the potential difference across the circuit as measured with a voltmeter. For alternating currents, however, it is usually necessary to include a third term, the power factor of the circuit. This will be discussed in a subsequent paragraph.

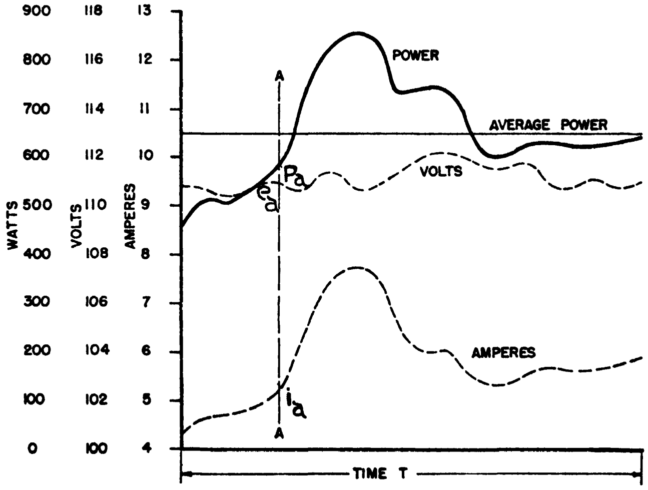


Fig. 3-1. Illustrating Instantaneous Values of Voltage, Current, Power and Average Power in a D-C Circuit Having a Variable Load

DIRECT-CURRENT CIRCUITS

The power in a direct-current circuit can be measured by means of a voltmeter and an ammeter. Generally in commercial metering, not the instantaneous value of the power as at A, Fig. 3-1, but the average power over some specified time interval T is desired. This is the average of all the instantaneous values of ei, and is indicated in the diagram by the horizontal line.

If the variations in voltage and current are small, the readings of the ammeter and the voltmeter may be averaged mentally and their product taken as the average power.

In cases where the current and voltage vary over a considerable range, it is preferable to obtain a number of ammeter and voltmeter readings in rapid succession and from these compute the average current, voltage and power. Another method of measuring power in a direct-current circuit is by means of a wattmeter which indicates the product of current and voltage.

ALTERNATING-CURRENT CIRCUITS

Single-Phase Circuits

In an alternating-current circuit both current and voltage are continuously undergoing a periodic variation in magnitude. Since the power is the product of these quantities, it will also vary correspondingly as illustrated in Figs. 3-2, 3-3 and 3-4. Fig. 3-2 shows the relation between current, voltage and power in an alternating-current circuit, where the load consists of resistance only. In this case the current and the voltage will reach their maximum values at the same instant and are said to be in phase. The maximum power will be the product of the maximum current and the maximum voltage, or $P_M = I_M E_M$.

However, the current and voltage in an a-c circuit are seldom completely in phase. Fig. 3-3 illustrates a case where the load contains inductance and the current lags the voltage by an angle θ. The power at any instant is still the

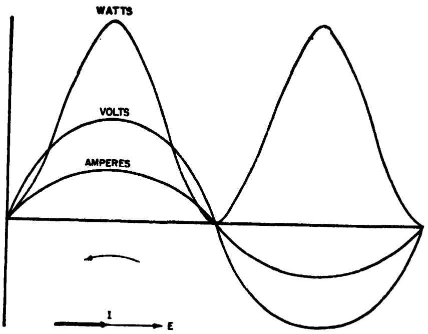


Fig. 3-2. Relation Between Current, Voltage and Power in a Simple A-C Circuit Containing Resistance Only

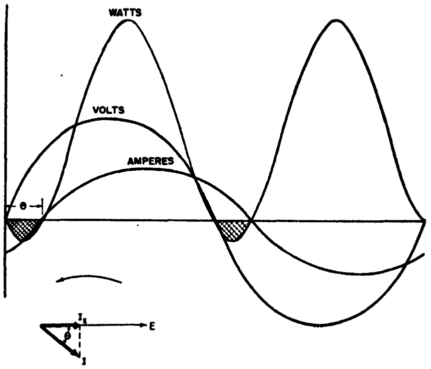


Fig. 3-3. Relation Between Current, Voltage and Power in an A-C Circuit Containing Inductive Reactance and Resistance

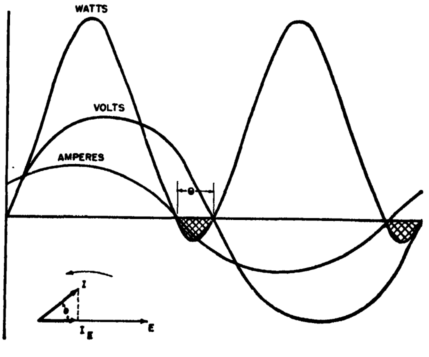


Fig. 3-4. Relation Between Current, Voltage and Power in an A-C Circuit Containing Capacitive Reactance and Resistance

product of the instantaneous values of current and voltage, but the maximum instantaneous power is no longer the product of the maximum current and the maximum voltage, because the current does not reach its maximum value until after the voltage has passed its maximum. The condition at the time the voltage is a maximum is illustrated by the small vector diagram at the bottom of Fig. 3-3. The effective current at this instant has the value I_E, and will be equal to $I \cos \theta$, where I is the maximum value of the current in the circuit. Instantaneous power at this time can be expressed in terms of the maximum value of current and voltage as $P_M = E_M I_M \cos \theta$. The cosine of the angle by which the current lags or leads the voltage impressed on the circuit is called the power factor of the circuit. If the circuit consists of inductance and resistance, the current lags the voltage and the circuit has a lagging power factor. If the circuit consists of capacitance and resistance, the current leads the voltage and the circuit has a leading power factor. Fig. 3-4 shows a case where the power factor is leading.

Ordinarily, alternating-current instruments do not indicate the maximum quantities but what is known as the "effective" or root-mean-square (rms) value. The rms current in a circuit is the square root of the average of the squares of all instantaneous values of current for one complete cycle. If the instantaneous values of current are $i_1, i_2, i_3, i_4, \ldots i_n$ then rms current =

$$I = \sqrt{\frac{(i_1)^2 + (i_2)^2 + (i_3)^2 + (i_4)^2 \ldots (i_n)^2}{n}}$$

A given number of rms amperes of alternating current, as measured with an ammeter, will cause the same heating in a non-inductively wound resistor as an equal number of amperes of direct current in the same resistance.

Alternating-current ammeters, voltmeters and wattmeters measure rms values and the expression previously given for power in terms of maximum current and voltage will also be correct for rms power, in terms of rms current and voltage.

Unless the power factor is known, power in an alternating-current circuit cannot be measured with a voltmeter and an ammeter, but requires the use of a wattmeter. In a wattmeter a stationary coil is connected in series with the load and a movable coil is connected in series with a resistance across the circuit. The reaction between the fields of these coils produces a torque which causes the movable coil to turn against the tension of a control spring. The torque and, therefore, the deflection of the movable coil is proportional to the product of the current in the circuit, the voltage across it, and the cosine of the angle between them. Since $P = EI \cos \theta$ and $\cos \theta = \frac{P}{EI} = \text{power factor}$ the power factor of a circuit can be determined by measuring the power with a wattmeter and the current and voltage with an ammeter and a voltmeter, and applying the values in the above formula.

Polyphase Circuits

A polyphase circuit consists of two or more single-phase circuits of the same system in which the respective voltages are not in phase. The individual circuits making up the polyphase circuit may be independent or interconnected and are referred to as the various phases of the circuit. A polyphase circuit is designated by the number of phases, such as a two-phase or a three-phase circuit. Although special use is made of six-phase and twelve-phase circuits, and in some cases other combinations, the meterman will rarely be called upon to meter them as such. The more common polyphase circuits are discussed here. A balanced load is said to exist in a polyphase circuit when the several phases have equal voltages, currents, and power factors.

Two-phase Circuits

In a two-phase circuit, the voltages differ in phase by 90 electrical degrees. The following forms are the most common:

(a) Two-phase, four-wire circuits (Fig. 3-5a) in which the two phases are entirely separate and independent single-phase circuits.

(b) Two-phase, three-wire circuits (Fig. 3-5b) in which the two phases are connected and have a common return.

(c) Two-phase, four- or five-wire circuits, in which the two phases are connected at the middle points of the phase windings (Fig. 3-5c). The middle point is often brought out as the fifth or neutral wire to the circuit.

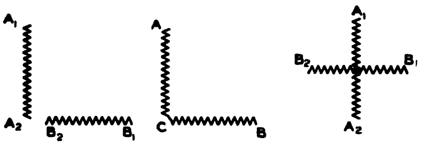


Fig. 3-5. Types of 2-Phase Circuits

Fig. 3-6 illustrates the vector relation of the voltages and currents in a balanced two-phase, three-wire circuit. The phase-to-common voltages E_{AC} and E_{BC} in the diagram are equal in value and differ in phase by 90°. The voltage between the two phase wires (or cross-phase) is the vector difference of the phase voltages and is designated as E_{AB}. Then, if E_P designates the phase-to-common voltage,

$$E_P = E_{AC} = E_{BC}$$

and

$$E_{AB} = \sqrt{E_{AC}^2 + E_{CB}^2} = \sqrt{2E_P^2} = \sqrt{2}\,E_P$$

The phase currents, designated as I_A and I_B in the diagram, will also be equal and will lag their respective voltages by angles θ. The phase angle between the two currents will be 90°, and the current in the common conductor (I_C) will be equal in magnitude to the vector sum of the phase currents, but opposite in phase. If I_P denotes the phase current, then

$$I_P = I_A = I_B$$

$$I_C = \sqrt{I_A^2 + I_B^2} = \sqrt{2I_P^2} = \sqrt{2}\,I_P$$

If the circuit is not balanced, and the current, or the power factor, or both, differ in the two phases, the current in the common conductor will likewise be equal in magnitude but opposite in phase to the vector sum of the two phase currents. Fig. 3-7 illustrates the vector relation of currents and voltages in an unbalanced system.

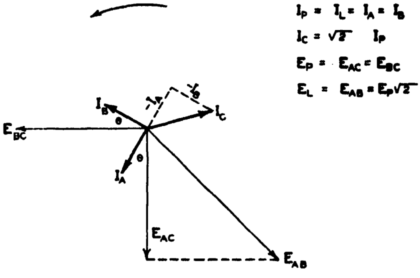


Fig. 3-6. Vector Diagram of Voltages and Currents in a 2-Phase, 3-Wire, Balanced System

The power in a two-phase circuit is the sum of the amounts of power in the two phases, and in a balanced circuit may be expressed by the equation:

$$P = 2\,E_P\,I_P \cos\theta$$

in which P equals the total power in watts, E_P the electromotive force in volts across each phase, I_P the current in amperes in each phase and cos θ the power factor.

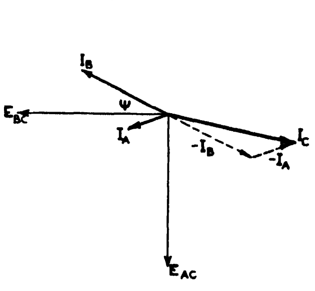


Fig. 3-7. Vector Diagram Illustrating a Method of Determining the Current in the Common Conductor of a 2-Phase, 3-Wire, Unbalanced System

Three-phase Circuits

In a three-phase circuit the voltages differ in phase by 120°. The following forms are the most common:

Three-phase, four-wire, star- or wye-connected (Fig. 3-8A).

Three-wire, open-wye (Fig. 3-8B), in which two phase wires and the neutral are used.

Three-phase, three-wire, delta-connected (Fig. 3-8C).

Three-phase, three-wire, open-delta or V-connected (Fig. 3-8D).

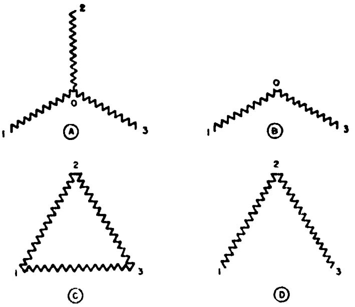


Fig. 3-8. Forms of 3-Phase Circuit

Fig. 3-9 shows two methods of developing a vector diagram for a balanced wye-connected system. It should be noted that the line voltage E_L, designated as E_{1-2}, E_{2-3} and E_{3-1} in the diagrams, are each equal to $\sqrt{3}$ times the phase voltage E_P, designated as E_{1-0}, E_{2-0} and E_{3-0}. The line current is equal to the phase current.

In any phase, the power is equal to

$$P_P = E_P I_P \cos\theta$$

where θ is the angle by which the phase current leads or lags the phase voltage. In a balanced three-phase, wye-connected circuit, the power in each phase is the same, therefore the total power will be three times the power in one phase, or

$$P = 3\,E_P I_P \cos\theta$$

Since the phase voltage E_P in a balanced wye-connected circuit is equal to the line voltage E_L divided by $\sqrt{3}$, and the phase current I_P is equal to the line current I_L, these values may be substituted in the equation as follows:

$$P = 3\,\frac{E_L}{\sqrt{3}}\,I_L \cos\theta$$

which is equal to

$$P = \sqrt{3}\,E_L I_L \cos\theta$$

This is the general expression for power in a three-phase balanced circuit, and applies regardless of whether the load is connected wye or delta.

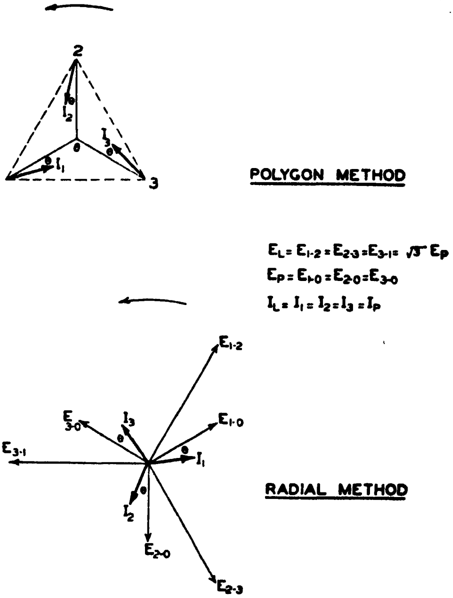


Fig. 3-9. Vector Diagram of Voltages and Currents in a 3-Phase, 4-Wire, Balanced Wye System

Fig. 3-10 shows two methods of developing a vector diagram for a balanced delta-connected system. In this case the phase voltages are equal to the line voltages and each line current is the vector difference of two phase currents. It will be seen that $I_L = \sqrt{3}\,I_P$ and that the line currents are displaced 30 degrees from the phase currents.

As stated previously, the power in any phase is equal to

$$P_P = E_P I_P \cos\theta$$

where E_P, I_P, and θ are the phase voltage, phase current and phase angle respectively. If these values are the same for each phase, the total power is

$$P = 3\,E_P I_P \cos\theta$$

Since $E_P = E_L$ and $I_P = I_L/\sqrt{3}$, the above equation may be expressed in terms of line quantities by substitution:

$$P = \sqrt{3}\, E_L I_L \cos \theta$$

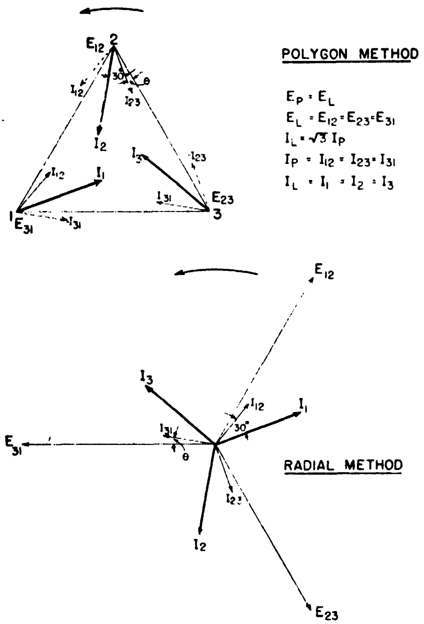


Fig. 3-10. Vector Diagram of Voltages and Currents in a 3-Phase, 3-Wire, Balanced Delta System

Indicating Wattmeters

For general purposes the simplest and most satisfactory method of measuring the power in an alternating-current circuit is by means of a wattmeter of the electro-dynamometer type. The same methods may be employed for averaging the readings as are described in methods for direct current.

Certain precautions should be taken when indicating instruments are used which are subject to frequency errors. They should only be used with the frequency for which they are designed; also, particular attention should be given to the wave form. The usual wave form, that is, the one best suited for economical operation, is the sine wave. Some types of apparatus, for example, certain forms of electrical furnaces, distort the wave to a considerable extent, and instruments which are subject to frequency errors will not indicate correct values.

Such a wave form may be resolved mathematically into components consisting of a fundamental and one or more harmonic waves, such as the third, fifth, seventh, etc. This is illustrated in Fig. 3-11 for a wave consisting of a fundamental and the third harmonic. The relative magnitude of the fundamental wave, and the number and magnitude of the harmonics determine the resultant wave form. If an instrument or a watthour meter is subject to frequency error, it is readily seen that if the harmonics are present and of appreciable magnitude, they may cause errors in the observed readings, since they are of different frequency than the fundamental. While such errors are known as wave-form errors, they are fundamentally errors due to frequency. Ordinarily, indicating instruments are not subject to wave-form errors outside of commercial limits of accuracy.

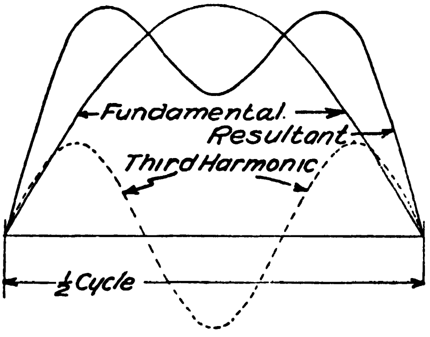


Fig. 3-11. Voltage Wave Form Made Up From a Fundamental and a Third Harmonic

Blondel's Theorem for Polyphase Circuit Power

Blondel has developed a theorem which applies to the measurement of power in a polyphase system of any number of wires with no restrictions as to the balance of the phases. The theorem is as follows:

> If energy be supplied to any system of conductors through N wires, the total power in the system is given by the algebraic sum of the readings of N wattmeters, so arranged that each of the N wires contains one current coil, the corresponding potential coil being connected between that wire and some point on the system which is common to all the potential circuits. If this common point is on one of the N wires and coincides with the point of attachment of the potential lead to that wire, the measurement may be made by the use of $N-1$ wattmeters.
>
> The receiving and generating circuits may be arranged in any desired manner and no assumption is made as to the way in which the voltages and currents vary.

Two-Wattmeter Method

According to this theorem the total power in a three-phase, three-wire circuit, either wye, open-wye, or delta-connected, may be measured by two wattmeters. (Three-phase, four-wire circuits would require three wattmeters.) Proof of this fact follows:

If we use instantaneous values of voltage and current in a three-phase circuit, with $\cos\theta = 1$, power would be expressed as

$$P = e_1 i_1 + e_2 i_2 + e_3 i_3$$

In any system such as the above, the instantaneous values of the currents in all phases must equal zero:

$$i_1 + i_2 + i_3 = 0$$
$$i_2 = -(i_1 + i_3)$$

Substituting for i_2

$$P = e_1 i_1 - e_2 i_1 - e_2 i_3 + e_3 i_3$$

Collecting terms

$$P = (e_1 - e_2)\, i_1 + (e_3 - e_2)\, i_3$$

In each case of discussion following this proof of the two-wattmeter method, W_1 is connected so as to measure the current i_1 and the voltage $(e_1 - e_2)$. Likewise W_2 is connected to measure the current i_3 and the voltage $(e_3 - e_2)$.

These same equations hold if the instantaneous values are replaced by rms values.

Referring to Fig. 3-9, W_1 will be connected to measure current I_1 and the voltage E_{1-2} which is $(E_{1-0}-E_{2-0})$. The angle between the current and voltage will be $\theta + 30°$. W_2 will be connected to measure I_3 and voltage E_{3-2} which is $(E_{3-0}-E_{2-0})$. The angle between the current and voltage will be $\theta - 30°$. The readings of the individual instruments will be:

$$W_1 = E\,I \cos(\theta + 30°)$$
$$W_2 = E\,I \cos(\theta - 30°)$$

The three-phase power will be

$$P = W_1 + W_2 = E\,I \cos(\theta + 30°) + E\,I \cos(\theta - 30°)$$

Substituting the equation for the cosine of the sum of two angles (from trigonometry) we have:

$$P = E\,I\,(\cos 30° \cos\theta - \sin 30° \sin\theta) + E\,I\,(\cos 30° \cos\theta + \sin 30° \sin\theta)$$

$$P = 2\,E\,I \cos 30° \cos\theta.$$

Since $\cos 30° = \dfrac{\sqrt{3}}{2}$

$$P = 2\,E\,I\,\frac{\sqrt{3}}{2}\cos\theta$$

$$P = \sqrt{3}\,E\,I\cos\theta$$

This is the general expression for power in a three-phase circuit as previously developed.

Referring back to the vector diagram of Fig. 3-9, it will be seen that for unity power factor, $\theta = 0$, the current in wattmeter W_1 lags the applied voltage by 30°.

As the phase angle increases in the lag direction, the reading of W_2 increases up to a point where $\theta = 30°$, at which point the current I_3 and the line voltage E_{3-2} are in phase. At the same time the reading of W_1 will decrease since I_1 will lag E_{1-2} by 60°.

As θ increases from 30° to 60°, both wattmeter readings decrease. When $\theta = 60°$, W_2 will measure I_3 lagging E_{3-2} by 30°, and W_1 will read 0 since I_1 will lag the voltage E_{1-2} by 90°. As this phase angle increases further the reading of W_1 reverses and is considered negative.

If leading power factors are encountered the reversed condition will hold, that is, W_1 will increase to a maximum, while W_2 decreases gradually to 0 and finally to a negative reading.

A similar analysis can be carried through for delta connected loads, using the vector diagrams of Fig. 3-10.

In the measurements of power by the two-wattmeter method, in three-phase circuits in which the power factor is below 0.50(60°), the readings of one wattmeter are negative. It is therefore necessary that the connections be so arranged that a negative deflection of the wattmeter signifies the reading should be subtracted when computing the power.

In order that there may be no confusion, the potential and current terminals of the wattmeters through which the current should enter when flowing from the generator to the load should be determined and marked on the instruments. The proper marking may be determined by connecting the instruments in a single-phase circuit. Then, whenever they are used, the currents as they flow from the generator to the load must enter both the current and potential coils at the marked terminals.

When the instruments are so connected, if the pointer deflects up the scale, the reading is positive; if the deflection is in the opposite direction, the reading is negative. To obtain its numerical value, the connections to the current or potential coils must be reversed and the readings so obtained regarded as negative. This simple procedure avoids all uncertainty as to the algebraic signs of the readings and renders unnecessary any special tests for their determination.

In Section 7 diagrams showing the connections for watthour meters are given. These diagrams, with very few exceptions, may be used for indicating instruments by substituting the current and voltage elements for the current or voltage element of the watthour meter. The exceptions are three-wire direct-current and three-wire single-phase alternating-current circuits, since three-wire indicating meters are not generally available. For the direct-current circuit two ammeters and two voltmeters, and for the single-phase alternating-current circuit two wattmeters, or a two-element wattmeter, would replace the three-wire watthour meter indicated in the diagram.

MEASUREMENT OF ENERGY

Energy is the summation of instantaneous power over a period of time, or it is the average power over a period of time multiplied by the time.

It has been explained that an indicating wattmeter measures the mechanical torque produced by the proper coils connected in series with the load and across the circuit and indicates electrical power.

To measure energy it is only necessary to summate or integrate these instantaneous values over a period of time. This can be done by using a device fundamentally similar to an electric motor, one winding of which is connected in series with the load and the other winding across the circuit. The torque of such a motor will, therefore, be proportional to the power and the total revolutions of the motor will be a measure of the energy consumed by the load. A watthour meter consists essentially of such a motor, a register for recording the number of revolutions and a magnetic brake. The register and magnetic brake are common to all types of watthour meters and will be described here. The different types of motor units will be considered in subsequent parts of this section.

REGISTER

The register is a means of recording revolutions of the meter shaft. It consists of a revolution counter arranged to read in kilowatthours.

MAGNETIC BRAKE

Normally there is very little friction present in meters, and if no additional retarding force other than friction were placed in the meter the rotating element would travel at a relatively high speed. The necessary retarding action is secured by a magnetic brake consisting of a metallic disk rotating in a field produced by permanent magnets. As the disk rotates in this field, a voltage is generated which causes eddy currents to flow in the disk as indicated in Fig. 3-12. These eddy currents in turn produce a magnetic field of their own, which reacts with that of the permanent magnet to cause retarding forces opposite to the driving force. This damping action increases proportionately with the speed of the disk since the rate at which the permanent magnet flux is cut determines the generated voltage and consequently the strength of the magnetic field set up by the eddy currents.

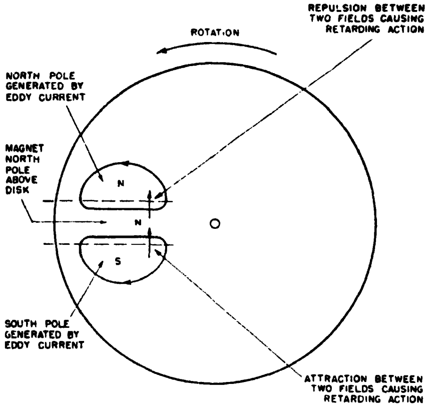

REPULSION BETWEEN TWO FIELDS CAUSING RETARDING ACTION
ROTATION
NORTH POLE GENERATED BY EDDY CURRENT
MAGNET NORTH POLE ABOVE DISK
N
N
S
SOUTH POLE GENERATED BY EDDY CURRENT
ATTRACTION BETWEEN TWO FIELDS CAUSING RETARDING ACTION

Fig. 3-12. Action of Braking Magnet on Rotating Disk

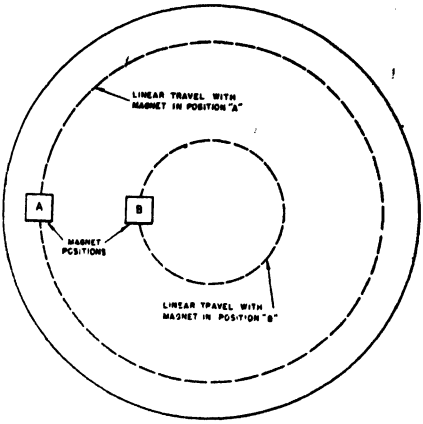

LINEAR TRAVEL WITH MAGNET IN POSITION "A"
A
B
MAGNET POSITIONS
LINEAR TRAVEL WITH MAGNET IN POSITION "B"

Fig. 3-13. Relative Travel of Disk Under Braking Magnet

It follows then that for the same torque, a certain area of the disk must pass under the magnet in a given time. Assuming a constant speed of rotation, a greater portion of the disk will pass between the magnet pole when the magnet is near the edge of the disk than when it is near the center. Hence, the braking torque will increase and the disk speed will decrease as the magnet is moved toward the outer edge of the disk (see Fig. 3-13).

Another common method used for adjusting the speed of the rotating element consists of a magnetic shunt placed near the poles of the magnet (Fig. 3-14). When this shunt is moved

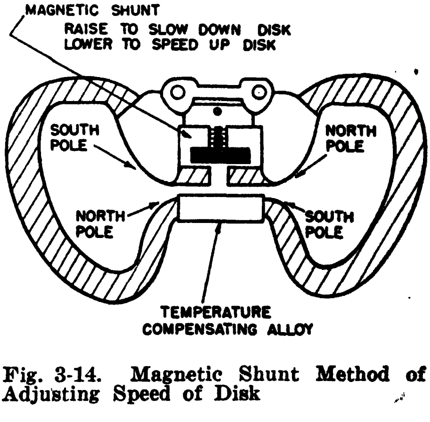


Fig. 3-14. Magnetic Shunt Method of Adjusting Speed of Disk

toward the pole faces, more magnetic flux passes through the shunt and less through the disk, increasing disk speed for a given torque, since the number of lines cut by the disk must remain constant for a given torque. The regulation of the retarding force of the magnetic brake by either or both the methods just described is used in adjusting the meter to record properly at full load.

Although permanent magnets as used on meters are in general very stable, their magnetism may be affected by a sharp blow, excessive temperature, a strong external field, or magnetic material placed between the poles of the magnets. Fig. 3-15 shows typical magnets used in a modern watthour meter. Actually this magnet is composed of two permanent magnets mounted astatically in a non-magnetic shoe. This shoe acts as a support which aids in fastening the magnet to some part of the watthour meter in a rigid manner.

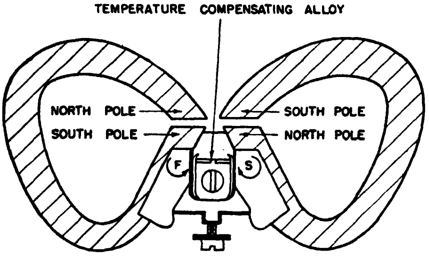


Fig. 3-15. Watthour Meter Magnets of Modern Design with Temperature Compensation

The polarity of the poles is marked in this figure to illustrate the astatic arrangement.

D-C WATTHOUR METERS

There are two types of direct-current watthour meters, the commutator type and the mercury motor type.

Commutator Type Meter

The motor element of this watthour meter is essentially a shunt motor with the field coil connected in series with the load and the armature connected across the line. Due to its weak magnetic field and slow rotation, it has negligible counter-electromotive force. Its armature current, therefore, is independent of the speed of rotation, and is practically constant for any definite value of voltage applied at its terminals. The torque of this motor, being proportional to the product of its armature and field currents, must vary directly as the power passing through its coils to the load circuit. In order then that the meter shall register correctly, it is necessary only to provide some means for making the speed proportional to the torque. This is accomplished by the use of the magnetic brake as previously described.

Friction Losses—A certain amount of frictional resistance is created by the bearings and registering mechanism. This friction must be overcome in order to obtain a speed of the disk on light load that is proportional to the power. This is accomplished by the use of an auxiliary coil connected in series with the potential circuit and placed in the same relation with respect to the armature as the main current coil. This coil is provided with an adjustment so that the torque produced by it can be adjusted to balance the friction of the meter.

Astatic Construction—Large capacity meters are usually manufactured with two armatures, mounted on the same shaft, and connected to a single commutator so that the direction of current flow of one armature will be opposite to the other. Two sets of field coils are used and arranged in a similar manner. Such construction is called astatic and minimizes errors due to stray fields from nearby conductors. It eliminates errors due to uniform external fields because these will produce equal and opposite torques in the two armatures.

Mercury-Motor Meter

The mercury motor consists essentially of a copper disk floated in mercury between the poles of a magnet and provided with conducting leads to and from the mercury at diametrically opposite points. In the mercury motor meter, rotation of the rotating element is caused by the interaction of the current flowing across the disk and the field of an electromagnet. The disk which acts as a current carrying conductor is free to revolve and the action of the electromagnetic field upon it causes it to shift, but due to the mercury carrying current into and out of the disk at diametrically opposite points, the path of the current does not change its relation to the electromagnetic field; therefore, the continual shift results in rotation.

In this type of meter, the usual lower jewel bearing is not necessary as the rotating element is supported by the mercury. A lower guide bearing is provided to keep the rotating element centered in the mercury chamber. To compensate for friction a thermocouple supplies a small current that flows across the disk, and the variation of this current for light-load adjustment is made with an adjustable resistance.

A-C WATTHOUR METERS

The principle of the a-c watthour meter is essentially that of a squirrel cage induction motor in which the principle of the rotating magnetic field is utilized to produce torque on the disk. See Fig. 3-16.

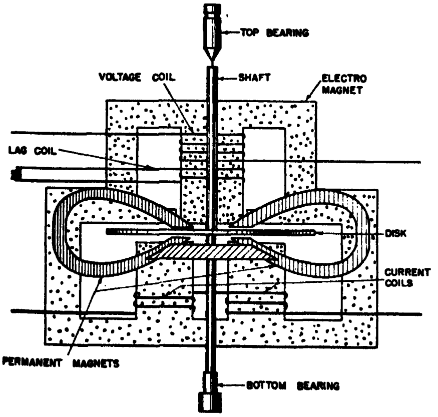


Fig. 3-16. Schematic Diagram of Single-phase Induction Watthour Meter

The resultant field of two alternating currents of like frequency, which are in time and space quadrature, is a true rotating magnetic field. If two currents differ in phase by 90 electrical degrees and flow in two coils placed at right angles to each other, the magnetic fields produced by these coils will also differ one from the other by 90 electrical and space degrees. The field strength of each coil continually varies, but the resultant field due to both coils is constant in magnitude when the currents have equal rms values. If the currents are not equal in magnitude, the magnitude of the resultant flux will not be constant, but will be proportional to the instantaneous values of the currents. The field strength of each coil will vary from zero to maximum positive, then to zero and maximum negative and again to zero in each cycle. The combined flux is progressive and continually shifting, approximating a rotating action.

The a-c watthour meter is designed so that the current and potential winding fluxes are displaced 90 degrees in space. The current coil current is in phase with the line current, but the potential coil current is practically 90 electrical degrees out of phase with the line potential due to the high inductance of this coil. Thus the requirements for a rotating or shifting field are met, and in the meter this field is passed through a portion of the disk. Thus, in the following example, it will be noted that first a south pole is caused to move across the face of the disk, then a north pole, etc.

In Fig. 3-17 the fields may be considered north polarity when their magnitude is indicated to the left of the vertical axis, and south polarity when to the right of the vertical axis. The figure shows the progress of these fields across the disk for various positions of the current and potential flux curves. Briefly, the action may be summarized from this figure which indicates the flux curves, the electromagnet polarity for several positions of these curves, and the summarized tabulation showing the progress of magnetic fields across the face of the disk.

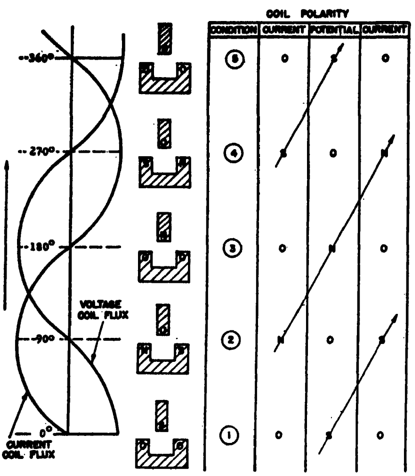


Fig. 3-17. Showing the Progress of the Magnetic Fields Across the Disk for Various Positions of the Current and Voltage Flux Curves

Condition 1—The current coils are at the zero point of the flux curve, but since the potential coil flux lags that of the current coils by 90° this curve is to the right of the line, and the potential coil develops a south magnetic pole.

Condition 2—The potential coil flux has reached zero as its potential is 90° from that of position 1. The current coil flux has reached a maximum and produces north and south poles as indicated.

Condition 3—This position is similar to that of position 1, except that the potential flux curve is to the left of the line; consequently a north pole is developed by that coil. The current coil flux has again reached zero.

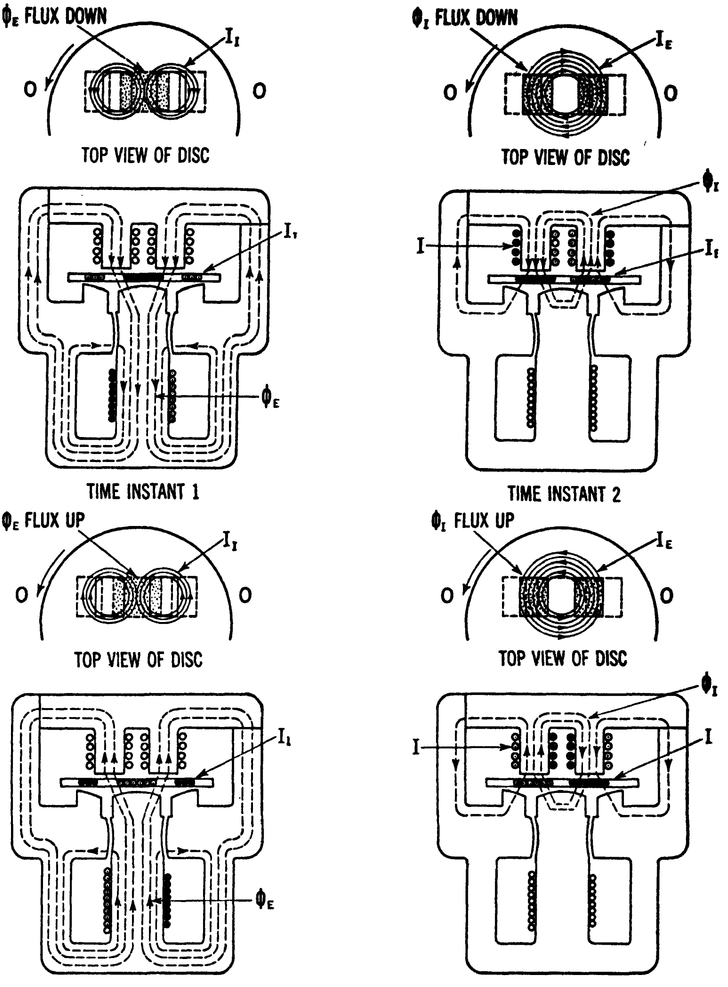
Condition 4—This position is similar to that of position 2, except that the current flux curve is to the right of the line; consequently the poles are in the reverse order to that shown for position 2. The potential flux is zero.

Condition 5—This completes the cycle of change and is a repetition of condition 1.

A glance at the summarized results to the right of the curves will indicate that first a south pole, then a north pole and then the south pole moves across the disk as indicated by the diagonal arrow in the tabulation. The action is similar to that described under magnetic braking, the only difference being that the field of the magnet shifts. Eddy currents are generated which react with this moving magnetic field causing attraction as previously described, except in this case the disk is free to move.

It is essential that the torque be maximum when the load to be metered is non-inductive and the torque on inductive loads be proportional to the cosine of the phase angle between the load current and voltage. When the successive values of the flux of a magnetic field follow a sine curve, the rate of flux change is greatest at the instant of crossing the zero line; consequently the induced current is greatest at this instant. The magnetic field is greatest at the maximum point in the curve. With two fields differing in phase relation, it is evident that in order for one field to be at zero value while the other is at maximum the phase difference must be 90°. Since the meter torque depends on the interaction between the field and induced current, it is evident that the greatest torque occurs when the phase separation is 90°. This is true at any instant throughout the cycle. When the two fields are in phase with each other, the induced current produced by one field will be in a definite direction which will not change while the field changes from a maximum negative to a maximum positive value. The other field in changing from a negative to a positive value would tend to change the direction of rotation. The change would occur every one-fourth cycle, and the resultant torque would be zero. This is true also when the fields are 180° apart.

Supplementing the previous discussion, it will be noted that the instant the voltage coil flux reaches a maximum value, there is no change in this flux; consequently no current is induced in the disk by this flux. The current-coil flux, although at the zero value, is changing at a maximum rate.



TIME INSTANT 1

TIME INSTANT 2

TIME INSTANT 3

TIME INSTANT 4

Fig. 3-18. Direction of Fluxes Through a Meter Disk Producing a Shifting or Rotating Field

Induced electromotive force and consequently induced current depend on the rate of flux change. Thus, eddy currents are induced in the disk. Fig. 3-18 shows these eddy currents flowing in the disk in the direction indicated by arrows. The four positions shown in this figure correspond to the condition numbers indicated in Fig. 3-17. It will be noted that for each of these conditions, the induced eddy currents react with the field which is at its maximum value to cause rotation as indicated.

The cosine of an angle of zero degrees is one and the cosine of 90° and 270° is zero. The actual torque produced by the two fields varies directly as the cosine of the angular difference plus or minus 90°. It is apparent from the above that if one field is proportional to the current in a power circuit and the other to the voltage across the circuit, the torque produced will be proportional to the product of these values. Further, that if an initial phase difference between the two fields is exactly 90° when the line current and voltage are in phase, the torque produced on the rotating element when the current and voltage are not in phase will be proportional to the cosine of the angle of phase difference. When the correct phase difference is obtained between the current and potential flux (i.e., when the meter is properly lagged), the meter can be used to measure the correct power in the circuit since the power is equal to the product of the voltage, current and power factor, the power factor being equal to the cosine of the phase difference between the current and voltage in the load circuit.

Multi-Element Meters

Multi-element meters are those having two or more complete single-phase meter elements arranged so that they drive the same shaft at a speed proportional to the power used through all the elements. A single register totalizes the energy measured by all elements.

Two- and three-element polyphase meters are conventional types of multi-element meters. Special multi-element meters have been manufactured for totalizing a number of polyphase circuits.

Some types of multi-element meters have a separate disk for each element with all disks on a single shaft, other types have all elements operating on one single disk.

Multi-Element Duplex Meters

These meters have two groups of meter elements mounted side by side, and each group has its own disks and shaft. The two shafts drive a common register through differential gearing.

Multi-Circuit Meters

These meters are similar to the conventional two- or three-element polyphase meters except each current coil has more than one current winding, depending on the number of circuits to be measured. These meters are limited to circuits from a common source because the potential coil must be connected to a common point.

The purpose of special multi-element or multi-circuit meters is to totalize a number of polyphase circuits. They are usually of the instrument transformer type.

METHODS OF COMPENSATING FOR ERRORS IN A-C METERS

Meters are provided with certain adjustments which permit their calibration at certain specified loads. However, they are required to operate over a wide range of load and power factor, some of which differ widely from the conditions under which the meter is calibrated. Meters are designed to measure accurately under all conditions. Some of the factors which the design engineer must consider in securing this overall performance are included here to provide a better understanding of the operation of the meter. Most of these factors are incorporated in the design of the meter and do not require adjustment. A few which are adjustable are so mentioned in the discussion which follows.

Temperature Compensation

In induction-type watthour meters, errors caused by variation in temperature may be classified as "class 1 errors" which are operative at all power factors and are of great importance, and "class 2 errors" which are negligible at unity power factor but become increasingly operative as the power factor decreases.

Broadly stated, class 1 errors are caused by changes in the magnitude of current, voltage or braking flux. Temperature variations result in internal changes in the permanent magnet, change in permanent magnet air gap, change in permeability in the magnetic circuits of the electromagnet, and a small change in magnitude of potential flux. In general, class 1 errors result in increased registration with increase in temperature.

It has been found that certain alloys of copper, nickel and iron, known as Thermalloy, properly treated, have magnetic properties that change proportionately with a change in temperature. Such material when used as a magnet shunt (Figs. 3-14 and 3-15) will compensate for class 1 errors. Temperature compensation is accomplished by designing the cross section of shunts of this material in such a manner as to give approximately accurate performance over a wide range of temperature. Briefly the action is as follows: As the temperature increases less flux is bypassed through the alloy shunt and consequently more flux passes through the disk, thus compensating for the temperature error.

It might appear that since aluminum is almost universally used in the disk, an error of 0.4% per degree Fahrenheit would result, since this figure is the approximate temperature coefficient of this metal. This is not true, for while there is a change in braking action due to an increase in resistance of this material, there is a corresponding decrease in driving torque for the same reason. These two changes are exactly equal and opposite so that the net result from this source is no change.

Class 2 temperature errors are negligible at or near unity power factor but increase rapidly as the power factor decreases. They are primarily due to changes in the effective resistances of the potential and lag circuits, which in turn cause a shift in the phase position of the potential flux. These errors have been greatly reduced in recent years by improved design of the potential element. Methods of compensating for the remaining errors have also been developed and are used in modern meters. One method is to place a small piece of material with negative permeability temperature characteristics around one end of the lag plate. The function of this alloy is to make the impedance of the lag plate circuit change with temperature in such a manner that it will compensate for class 2 errors over a wide range of temperature. Another method is to over-lag the potential flux, using a lag plate with a low temperaure coefficient, and then to bring the current and potential fluxes back into their proper relationship by lagging the current flux with a copper lag plate.

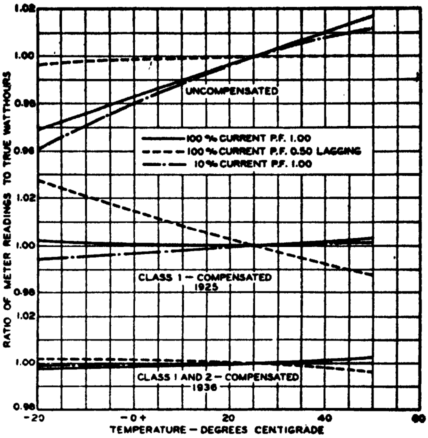


Fig. 3-19. Temperature Characteristic Curves of Watthour Meters

Uncompensated meters will be affected by temperature to some extent. At high temperatures the resistance of the lag coil increases, which causes the meter to be under-lagged. This results from a decrease in the current induced in the lag coil because of increased resistance and also because of an increase in losses in the potential circuit. Under-lagging will cause under-registration at lagging power factors. This effect is opposite for leading power factors and results in over-registration for this condition. The effect on lagging power factor is opposed to those which affect the counter-torque or braking action since these tend to cause the meter to over-register. The result of these two factors effectively reduces the error under the usual operating conditions.

With temperatures below that at which the meter was calibrated the opposite effects occur, the meter tends to be over-lagged, which results in a speeding up or over-registration at lagging power factors and under-registration at leading power factors. In every case these errors subtract from those caused by the braking action.

Of the several sources of class 1 temperature errors, the most important is the weakening of the permanent magnets with increase of temperature which results in increased speed of the meter. However, this effect is only temporary, for the loss in strength is restored when the magnets return to normal temperature. The predominant source of class 2 errors is the change in resistance of the potential winding which reacts to decrease the 90° phase relation between the driving fluxes with any increase in ambient temperature.

Fig. 3-19 shows the temperature characteristic of modern watthour meters and indicates the high degree of temperature compensation which has been secured by the methods previously outlined. Meters which do not have this compensation show a tendency to over-register as the temperature increases.

Friction Compensation

In alternating-current induction-type meters the shaded-pole principle of producing torque is used to compensate for friction. Essentially a short-circuited turn of large cross section, usually a plate or punching of sheet brass or other suitable material, is placed in the air gap above or below the disk, or around the main potential pole, so as to embrace part of the potential coil flux. This shading loop, if symmetrical with the pole, acts only as a lag plate and will produce no torque on the disk. If, however, it is moved laterally across the path of the potential flux to an unsymmetrical position with respect to the pole, a slight displacement is sufficient to provide the necessary torque for light-load calibration. In operation the potential coil flux reaches a maximum value, at which time that part of the potential coil flux passing through the loop is still increasing due to the lagging effect of the compensator coil. That portion of the flux which is increasing causes an induced voltage and eddy currents in the disk which react with the remaining flux to develop the slight torque required to overcome friction.

Lag Adjustment

Due to the resistance of the wire composing the potential coil and the iron loss in the core, it is impossible to obtain a purely reactive circuit providing an exact 90° displacement between current and voltage. To accomplish this another coil is added to the pole upon which the voltage coil is located. This coil consists of one or more short-circuited turns in which, due to transformer action, current is induced, and in turn sets up a field of its own. The field of this coil and that of the voltage coil combine to produce a resultant field that lags that of the current coils by the proper amount. Adjustment is obtained either by changing the position of this coil radially with respect to the disk or by changing the resistance of the coil circuit. This adjustment once made seldom requires change. Refer to methods of compensating for class 2 temperature errors.

All induction-type meters should be compensated or lagged, in order that the angle of phase difference of the magnetic fields produced by the current coil and voltage coil will be exactly 90° when the power factor of the applied load is unity. When the power factor of the applied load is not unity and the current in the circuit to be measured leads or lags the voltage by the angle θ, the angle of phase displacement between the fluxes produced by the voltage and current coils in the meter will be 90° plus or minus θ. When the current in the circuit lags the voltage the sign of the angle θ should be minus, and when the current leads, the sign should be plus. The sine of the resultant angle between the fluxes will be equal to cosine θ, the power factor of the load circuit.

The torque exerted upon the disk is then proportional to the cosine of the angle of lag or lead of the current and is also proportional to the product of the voltage and current fluxes which are, in turn, proportional to the currents causing them. Consequently, the torque varies directly as the true power transmitted or as $EI \cos \theta$.

In explanation of the relation between the voltage and lag coils of a watthour meter, these coils are comparable to the primary and secondary coils respectively of a transformer with large leakage reactance.

Fig. 3-20 shows the paths of the various magnetic fluxes, and Fig. 3-21 is a vector diagram indicating the phase relations between these fluxes and the currents producing them.

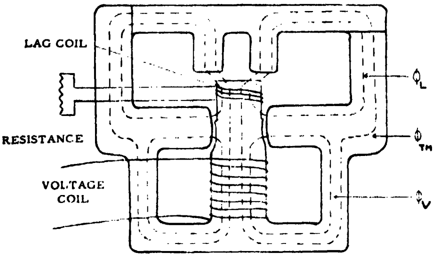


Fig. 3-20. Paths of Magnetic Fluxes

E represents the magnitude and direction of the impressed voltage. I_V represents the current in the voltage coil. As the voltage coil is highly inductive, I_V lags considerably behind the impressed voltage E. The angle of lag θ is less than 90° due to the IR drop in the voltage coil.

The flux produced by I_V is divided in several paths as shown in Fig. 3-20. The flux represented by ϕ_V is in phase with and proportional to I_V. ϕ_{VM} indicates the paths of the flux from the voltage coil which cuts the disk. This flux is mutual to both the voltage coil and the short-circuited lag coil and is practically in phase with, and its magnitude is proportional to, the vector sum of the current in the voltage coil and the induced current I_L in the short-circuited lag coil.

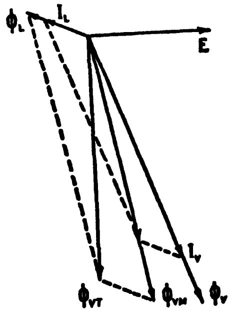


Fig. 3-21. Phase Relation Between Fluxes and Currents

ϕ_L indicates the flux produced by the induced current I_L in the lag coil. It is in phase with and proportional to I_L.

ϕ_{VT} represents the total resultant flux passing through the meter disk which, by interaction with the disk currents, produces the meter torque. ϕ_{VT} is equal to the vector sum of the fluxes ϕ_{VM} and ϕ_L.

It is apparent that by changing the resistance in series with the lag coil, the current I_L induced in this coil and consequently the flux ϕ_L is changed and the phase angle between the total flux passing through the meter disk and the disk currents is adjustable by this means within definite limits.

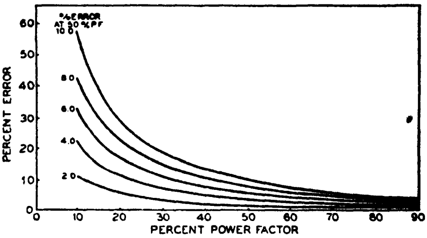


Fig. 3-22. The Effect on Meter Registration for Lagging Power Factors When Improper Adjustment Has Been Made at 50% Power Factor

Watthour meters are so designed that this phase angle can be adjusted to zero degrees when the current in the current coil is in phase with the impressed voltage. Once the proper phase relationship between the load current flux and the potential flux is attained there will be no discernible error at any power factor. If this adjustment is improperly made an error will be present at all power factors other than unity and this error will increase as the power factor decreases. This is shown graphically in Fig. 3-22, which was calculated as follows:

per cent error =

$$100\left(1 - \frac{\text{meter watts}}{\text{standard watts}}\right)$$

Which may be resolved into the following:

per cent error =

$$100\left(\frac{\cos\theta - \cos(\theta \pm \phi)}{\cos\theta}\right)$$

where θ is the angle between the line current and voltage and ϕ is the angle of error between the line current flux and the potential flux due to improper relation within the meter. These data were computed without reference to errors of calibration at full load. Such errors are independent of those in Fig. 3-22 and add to or subtract from these, dependent upon their relative signs. The errors indicated, while computed for lagging power factor, are also applicable for leading power factor. The sign of the effect will change in going from a lagging power factor to a leading power factor. In other words, an improper lag adjustment which causes the meter to run slow on lagging power factor will cause it to run fast on leading power factor.

Driving-Torque Balance for Multi-Element Meters

Balance adjustment is required in multi-element meters only. Since it is impracticable to obtain on a production basis elements that will give exactly the same response in driving torque, it becomes essential that an adjustment be provided. One type of adjustment provides a radial motion to the entire element in relation to the disk. Another type changes the effective potential flux by the use of an adjustable magnetic shunt.

LOAD CHARACTERISTICS

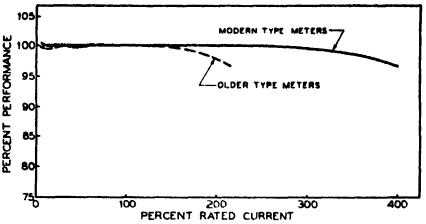


Fig. 3-23. Comparison of Composite Performance Curves of Modern and Older Type Watthour Meters Over an Extended Load Range at Unity Power Factor

Fig. 3-23 shows the load characteristic curve of a modern type meter compared with that for an older type meter built prior to 1925. These data were compiled from the composite characteristics of several manufacturers' products. As a result of this development, the number of meter sizes necessary to cover the self-contained meter load range has been reduced to three, i.e., the 5, 15 and 50 ampere sizes. Two factors that determine the shape of the load curve are especially important, one of which has its greatest effect on light loads and the other on very heavy loads.

At light loads an important factor is the ratio of torque to friction. The present-day meters have effective devices for compensating for friction, as explained elsewhere.

If the friction is variable or changes after the compensation adjustment has been made, the effect on the meter accuracy will depend upon the driving torque of the meter. If the driving torque is high, the effect upon the accuracy of the meter is less than in those cases where the torque is low.

The accuracy at heavy loads is also dependent upon the torque and the manner of developing it. Increases in torque may be accomplished by changes in any one or several of the following items:—Potential coil ampere turns, current coil ampere turns, thickness and conductivity of the disk, volume and kind of iron in the electro-magnetic circuits, air gap and radius of action of the torque producing element. However, various other important characteristics are also determined by these quantities, the relationship of which forms some of the chief technical concerns of the meter designer.

The ratio of the damping element flux to the effective flux produced by the series circuit determines the overload characteristic. The disk, in cutting through the series circuit flux has eddy currents produced in it which react with the flux from the electro-magnet to cause an additional damping action similar to that previously described for the permanent magnet. This additional damping action is proportional to the square of the electromagnetic flux, and while not noticeable on small loads, will cause serious deviations from accuracy on heavy overloads. Thus, if we arbitrarily choose one (1) as the braking component produced by electro-magnetic flux at 100% rated meter capacity, the component produced by the same cause at 400% rated capacity will be sixteen (16).

This effect may be minimized in several ways:

1. By means of a magnetic shunt placed across the poles of the current electro-magnet, and separated from these by thin spacers of non-magnetic material. It will have practically no effect upon the shape of the accuracy curve below the point where the overload droop begins in an uncompensated meter of the same type. As the load is increased beyond this point the shunt will gradually approach saturation and, consequently, that part of the current flux which passes through the disk will gradually increase. The resultant increase in torque will counteract the normal droop in accuracy until a point is reached, at several hundred per cent load, where the shunt is completely saturated. Beyond this point the droop of the curve will be very pronounced.
2. By proper proportioning of the voltage and current fluxes. For a given torque, if the voltage flux is increased at the expense of the current flux, the damping effect of the series coil flux will be lowered.
3. By using stronger permanent magnets and reducing disk speed. This would increase the ratio of damping magnet flux to series circuit flux and thus improve overload registration.

Variations in thickness or conductivity of the disk result in corresponding changes in the driving torque, but produce directly equivalent changes in the counter-torque or braking action. They also modify the friction compensating torque which determines one of the voltage characteristics and the dependability of the light load adjustment.

Changes in the distance of the torque producing element from the center of the disk cause corresponding changes in torque, but do not modify the overload loss in registration since the damping effect of the current circuit flux is also dependent upon the distance from the center of the disk. Variation in the position of the electromagnet radially along the disk would in general mean larger disks, greater bearing friction and more costly design.

Changes in volume and cross section of the iron contained in the electromagnet would not affect the change in performance at overloads, for while changes in the iron would cause a corresponding change in torque, this would be counterbalanced by changes in the series circuit damping.

VOLTAGE CHARACTERISTICS

The voltage characteristic of a meter is shown in Fig. 3-24. The voltage errors of induction meters over the usual range of voltage variation are extremely small.

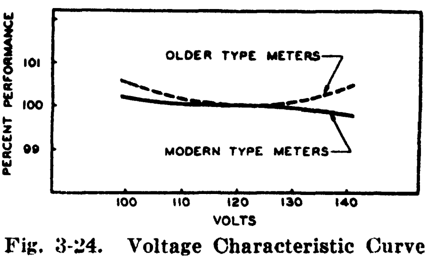


Fig. 3-24. Voltage Characteristic Curve

There is an action that is similar to that which causes the overload droop. A certain amount of damping is present from the cutting of the potential element flux by the disk. The eddy currents induced thereby are just as effective for damping as similar ones induced by the permanent magnets. A variation in voltage results in a corresponding variation in this flux. The damping action varies as the square of the change. If the total potential flux is large in comparison with the damping magnet flux, these changes in potential damping will be of importance for relatively small changes of voltage. If the potential flux is of comparatively small magnitude larger changes of voltage are possible before serious errors develop. The voltage error will be present at all loads and independent of the value of current flowing in the series element. It tends to slow down the meter for increasing voltage, and to speed up the meter for decreasing voltage.

Another source of error may be in the magnetic characteristics of the potential laminations. A voltage change which would materially raise or lower the average magnetic permeability would result in a change in the value of the flux crossing the air gaps and this would result in a corresponding error. Good design materially lessens the possibility of this form of inaccuracy. Proper choice of the maximum density will give permeabilities which do not materially shift under rather wide ranges of magnetomotive force. The air gaps are also designed with sufficiently high reluctance to mask small variations in iron reluctance (permeability).

A third source of error lies in the action of the light-load or friction compensating device. If the ratio of torque to friction is low at low loads the compensation is correspondingly high. As this compensation is derived from the flux of the potential circuit, variations in potential are more serious than in those cases where the friction torque at light loads is small in comparison with the driving torque. There is no general action that would cause the friction to change with voltage so the resulting tendency is for over-registration with increase of voltage at light loads. Except for unusually wide variations in voltage the shift of accuracy will not be appreciable at 20% to 25% load. With over-voltages of sufficiently high value, creeping will occur.

FREQUENCY CHARACTERISTIC

The factors contributing to frequency errors are complicated and the resulting error is negligible for the frequency range encountered on present day systems. A technical discussion of the effect of frequency on the watthour meter is contained in the 1923 edition of this handbook.

The frequency characteristic of modern types of meters has been improved as indicated in Fig. 3-25.

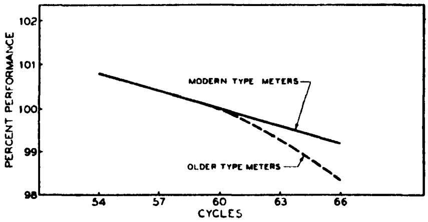


Fig. 3-25. Frequency Characteristic Curve

WAVE FORM DISTORTION

All alternating-current watthour meters are designed to operate on a sine wave. In practice, irregular waves may be encountered. However, all irregular alternating-current waves may be broken down into several sine waves of various harmonics and the fundamental sine wave. For instance, an irregular wave may be produced by a combination of the fundamental frequency and the third harmonic which is a wave having a frequency of three times that of the fundamental wave.

A fact of prime importance is that the final torque of the meter is the summation of torques due to the various harmonics. A particular harmonic in the potential wave reacts only with the same harmonic in the current wave to cause torque. If it is absent from either, no torque is produced. In practice, except in extreme conditions, no serious errors are produced due to wave form distortion. Where such extreme conditions exist, each case must be analyzed separately since no general characteristics can be given to cover wave form errors. A technical discussion of this subject is contained in the 1923 edition of this handbook.

METHODS OF CONNECTION

Methods of connecting watthour meters to measure energy on direct-current and alternating-current circuits are shown in Section 7.

POWER FACTOR DETERMINATION

The determination of the power factor of a circuit, particularly polyphase, presents many opportunities for erroneous procedure. To avoid any confusion in applying this term to measurements, particularly where refinements are necessary, the following facts and concepts should be carefully observed.

The *power factor* of a circuit is the ratio between the active power and the apparent power. The power factor of a circuit is never greater than unity. The power factor of a circuit in which a sine voltage causes a sine current to flow is equal to the cosine of the phase angle between the voltage and the current.

In a *balanced polyphase* system the currents and the voltages are symmetrical. The term balanced polyphase system is applied also to a quarter-phase (or two-phase) system in which the voltages have the same wave form and rms value, and in which the currents have the same wave form and rms value but differ in phase by 90 electrical degrees.

When the power is measured by one or more wattmeters for single-phase, two-phase or three-phase circuits, the power factor of each measured circuit is equal to the power in watts indicated by each wattmeter divided by the product of the voltage across the voltage circuit of the wattmeter and the current in the current coil of the wattmeter.

When the power is measured by one wattmeter for a two-wire single-phase circuit, power factor may be determined by connecting an additional wattmeter with its current coil in series with that of the first wattmeter, and its potential coil connected to an equal voltage displaced 90° from that applied to the wattmeter connected for the power measurement. The additional wattmeter then measures reactive power in vars, and instruments in which the required 90° shift in phase is provided internally, or by means of accessories, are known as varmeters. From the measurements so obtained the power factor may be determined from the formula:

$$\text{power factor} = \cos\left(\tan^{-1}\frac{P_x}{P}\right)$$

where P_x = the reactive power in vars, and

P = the active power in watts.

The integrated active power and integrated reactive power during a time interval are sometimes combined to yield an approximation to the mean power factor during the interval by the formula:

$$\text{power factor} = \cos\left(\tan^{-1}\frac{P_xt}{Pt}\right)$$

where P_xt = the product of reactive power and time (measured by a varhour meter) and

Pt = the product of active power and time (measured by a watthour meter).

The quantity thus defined is the "interval" power factor during the period over which readings were taken. This method can be extended to polyphase circuits.

In practical application, the power-factor chart in Table 3-A is useful. Divide the varhours by the watthours (or the vars by the watts). Select from Table 3-A the figure that agrees with this result as closely as possible, and in the column on the left read the power factor to two decimal places. The third decimal figure may be obtained from the top of the column in which the figure appears.

The power factor of a balanced polyphase circuit is the same as the power factor of any one of the receiving circuits.

The power factor for a *single-phase* circuit may be determined by dividing the watts, as measured with a wattmeter, by the product of the current and voltage.

$$\text{Power factor} = \frac{W}{EI} = \frac{\text{watts}}{\text{volt-amperes}}$$

For sinusoidal wave forms of voltage and current, the value thus obtained equals cos θ. Since readings taken from suitable indicating instruments are not ordinarily subject to wave-form errors outside the commercial limits of accuracy, the power factor can be taken as equal to cos θ for commercial measurements.

In a *balanced* three-phase, three-wire circuit the power factor may be readily determined from two wattmeter measurements or from measurements with two watthour meters.

The equation for determining the power factor of a balanced three-phase, three-wire circuit with two wattmeters is:

$$\tan\theta = \sqrt{3}\,\frac{W_2 - W_1}{W_2 + W_1}$$

where θ is the angle of lag or lead of the current, and W_1 and W_2 the readings of the wattmeters. The larger reading is W_2 and is always positive; the small reading W_1 may be either positive or negative.

$$\text{Power factor} = \cos\theta$$

Since the time in seconds for a specific number of revolutions of a watthour meter is inversely proportional to the load in watts, we may substitute for the above equation the following:

$$\tan\theta = \sqrt{3}\,\frac{S_1 - S_2}{S_1 + S_2}$$

where S_1 and S_2 are the time in seconds for a specific number of revolutions of watthour meters W_1 and W_2 respectively. W_1 and W_2 may be two single-phase meters, or the two elements of a polyphase watthour meter. Table 3-B furnishes a convenient means for determining the power factor corresponding to different values of the ratio

$$\frac{W_1}{W_2} \text{ or } \frac{S_2}{S_1}$$

Examples Showing Use of Table 3-B—Given a polyphase meter, the watthour constant of which is 6. With the potential circuit of only one element energized, the meter makes 10 revolutions in 52.7 seconds, and with only the potential circuit of the other element energized, 2 revolutions in 30.9 seconds. To find the power factor:

S_2 for 10 revolutions = 52.7 seconds
S_1 for 10 revolutions = 30.9 ÷ 2 × 10 = 154.5 seconds

$$\frac{S_2}{S_1} = \frac{52.7}{154.5} = 0.341$$

From the table, cos θ (power factor) corresponding to $\frac{S_2}{S_1} = 0.341$ is 0.76 +

The watts corresponding to $S_2 = 52.7$ and $S_1 = 154.5$ seconds are 4100 and 1400 respectively.

$$\frac{W_1}{W_2} = \frac{1400}{4100} = 0.341 \text{ or } \cos\theta =$$

0.76 as before.

TABLE 3-A

POWER FACTOR CHART

p f	0	1	2	3	4	5	6	7	8	9
1.00	0									
0.99	0.1425	0.1351	0.1272	0.1190	0.1100	0.1004	0.0897	0.0777	0.0634	0.0448
0.98	0.2031	0.1978	0.1923	0.1868	0.1811	0.1752	0.1691	0.1629	0.1563	0.1496
0.97	0.2506	0.2462	0.2418	0.2372	0.2326	0.2279	0.2231	0.2183	0.2133	0.2083
0.96	0.2917	0.2878	0.2838	0.2799	0.2758	0.2718	0.2676	0.2635	0.2592	0.2550
0.95	0.3288	0.3252	0.3214	0.3179	0.3143	0.3105	0.3067	0.3032	0.2994	0.2956
0.94	0.3630	0.3597	0.3564	0.3528	0.3495	0.3460	0.3427	0.3391	0.3356	0.3323
0.93	0.3953	0.3921	0.3889	0.3859	0.3825	0.3792	0.3762	0.3729	0.3696	0.3663
0.92	0.4261	0.4231	0.4200	0.4169	0.4139	0.4108	0.4078	0.4047	0.4015	0.3983
0.91	0.4557	0.4526	0.4498	0.4470	0.4438	0.4411	0.4379	0.4350	0.4320	0.4289
0.90	0.4843	0.4816	0.4788	0.4759	0.4731	0.4702	0.4672	0.4642	0.4614	0.4585
0.89	0.5123	0.5095	0.5068	0.5040	0.5011	0.4984	0.4957	0.4928	0.4899	0.4870
0.88	0.5398	0.5369	0.5343	0.5315	0.5287	0.5261	0.5233	0.5206	0.5178	0.5150
0.87	0.5667	0.5641	0.5614	0.5587	0.5560	0.5532	0.5505	0.5479	0.5452	0.5426
0.86	0.5934	0.5906	0.5881	0.5855	0.5828	0.5801	0.5774	0.5746	0.5721	0.5694
0.85	0.6196	0.6172	0.6144	0.6118	0.6092	0.6066	0.6040	0.6013	0.5987	0.5961
0.84	0.6459	0.6432	0.6408	0.6381	0.6354	0.6330	0.6301	0.6277	0.6249	0.6224
0.83	0.6720	0.6694	0.6669	0.6642	0.6615	0.6590	0.6565	0.6538	0.6511	0.6486
0.82	0.6980	0.6954	0.6929	0.6902	0.6877	0.6849	0.6824	0.6798	0.6773	0.6745
0.81	0.7239	0.7214	0.7188	0.7163	0.7135	0.7111	0.7085	0.7059	0.7032	0.7006
0.80	0.7499	0.7474	0.7447	0.7422	0.7395	0.7371	0.7344	0.7319	0.7292	0.7265
0.79	0.7761	0.7734	0.7708	0.7683	0.7657	0.7632	0.7604	0.7579	0.7552	0.7526
0.78	0.8023	0.7997	0.7971	0.7945	0.7919	0.7893	0.7865	0.7839	0.7813	0.7787
0.77	0.8287	0.8261	0.8234	0.8206	0.8180	0.8154	0.8127	0.8103	0.8077	0.8050
0.76	0.8551	0.8526	0.8498	0.8471	0.8446	0.8418	0.8391	0.8366	0.8339	0.8312
0.75	0.8819	0.8793	0.8765	0.8739	0.8711	0.8685	0.8657	0.8632	0.8603	0.8578
0.74	0.9089	0.9062	0.9036	0.9009	0.8980	0.8955	0.8928	0.8899	0.8873	0.8847
0.73	0.9363	0.9336	0.9306	0.9279	0.9252	0.9225	0.9198	0.9172	0.9145	0.9115
0.72	0.9637	0.9612	0.9584	0.9556	0.9528	0.9501	0.9473	0.9446	0.9418	0.9391
0.71	0.9919	0.9890	0.9861	0.9833	0.9807	0.9779	0.9750	0.9722	0.9694	0.9666
0.70	1.0203	1.0173	1.0144	1.0117	1.0088	1.0058	1.0032	1.0003	0.9974	0.9948
0.69	1.0489	1.0461	1.0431	1.0404	1.0373	1.0346	1.0316	1.0289	1.0259	1.0230
0.68	1.0783	1.0752	1.0724	1.0694	1.0664	1.0637	1.0606	1.0578	1.0547	1.0519
0.67	1.1080	1.1051	1.1020	1.0990	1.0961	1.0930	1.0900	1.0872	1.0840	1.0812
0.66	1.1383	1.1352	1.1323	1.1293	1.1260	1.1230	1.1200	1.1171	1.1139	1.1111
0.65	1.1692	1.1660	1.1629	1.1599	1.1568	1.1538	1.1506	1.1474	1.1443	1.1413
0.64	1.2005	1.1974	1.1943	1.1910	1.1878	1.1848	1.1816	1.1785	1.1754	1.1722
0.63	1.2327	1.2294	1.2261	1.2229	1.2198	1.2167	1.2135	1.2102	1.2070	1.2038
0.62	1.2655	1.2621	1.2589	1.2557	1.2524	1.2489	1.2456	1.2426	1.2393	1.2360
0.61	1.2989	1.2957	1.2923	1.2888	1.2857	1.2822	1.2788	1.2753	1.2723	1.2689
0.60	1.3335	1.3299	1.3262	1.3230	1.3194	1.3162	1.3127	1.3091	1.3059	1.3024
0.59	1.3684	1.3650	1.3613	1.3580	1.3543	1.3511	1.3473	1.3438	1.3404	1.3367
0.58	1.4045	1.4008	1.3972	1.3937	1.3899	1.3865	1.3827	1.3792	1.3755	1.3722
0.57	1.4415	1.4379	1.4340	1.4304	1.4266	1.4229	1.4193	1.4154	1.4120	1.4080
0.56	1.4792	1.4756	1.4718	1.4678	1.4641	1.4605	1.4565	1.4527	1.4490	1.4451
0.55	1.5185	1.5147	1.5105	1.5066	1.5027	1.4988	1.4951	1.4910	1.4872	1.4835
0.54	1.5587	1.5547	1.5507	1.5465	1.5425	1.5384	1.5345	1.5304	1.5262	1.5224
0.53	1.6000	1.5958	1.5916	1.5875	1.5834	1.5792	1.5751	1.5711	1.5667	1.5627
0.52	1.6426	1.6383	1.6340	1.6297	1.6255	1.6212	1.6170	1.6128	1.6083	1.6042
0.51	1.6864	1.6820	1.6775	1.6731	1.6687	1.6643	1.6599	1.6555	1.6512	1.6469
0.50	1.7321	1.7274	1.7228	1.7182	1.7136	1.7090	1.7045	1.6999	1.6954	1.6909
0.49	1.7790	1.7742	1.7965	1.7648	1.7600	1.7554	1.7506	1.7460	1.7413	1.7367
0.48	1.8276	1.8227	1.8178	1.8128	1.8080	1.8031	1.7983	1.7934	1.7886	1.7838
0.47	1.8780	1.8728	1.8678	1.8627	1.8576	1.8526	1.8476	1.8426	1.8376	1.8327
0.46	1.9303	1.9250	1.9197	1.9144	1.9091	1.9039	1.8986	1.8935	1.8883	1.8832
0.45	1.9846	1.9791	1.9736	1.9680	1.9626	1.9572	1.9518	1.9463	1.9408	1.9356
0.44	2.0410	2.0352	2.0295	2.0238	2.0181	2.0125	2.0069	2.0012	1.9957	1.9901
0.43	2.0997	2.0937	2.0877	2.0817	2.0758	2.0700	2.0641	2.0583	2.0525	2.0467
0.42	2.1608	2.1546	2.1484	2.1422	2.1361	2.1299	2.1238	2.1177	2.1116	2.1056
0.41	2.2248	2.2181	2.2116	2.2053	2.1988	2.1924	2.1861	2.1797	2.1733	2.1670
0.40	2.2912	2.2845	2.2778	2.2710	2.2642	2.2576	2.2510	2.2443	2.2377	2.2311
0.39	2.3611	2.3539	2.3469	2.3398	2.3328	2.3258	2.3189	2.3119	2.3050	2.2982
0.38	2.4342	2.4268	2.4194	2.4119	2.4046	2.3972	2.3900	2.3827	2.3754	2.3683
0.37	2.5110	2.5031	2.4953	2.4876	2.4799	2.4721	2.4645	2.4569	2.4493	2.4417
0.36	2.5916	2.5833	2.5751	2.5670	2.5588	2.5508	2.5427	2.5347	2.5267	2.5189
0.35	2.6764	2.6678	2.6591	2.6506	2.6420	2.6335	2.6250	2.6166	2.6082	2.5999
0.34	2.7660	2.7569	2.7477	2.7386	2.7295	2.7207	2.7117	2.7029	2.6940	2.6852
0.33	2.8606	2.8508	2.8413	2.8317	2.8221	2.8126	2.8032	2.7939	2.7845	2.7752
0.32	2.9608	2.9504	2.9403	2.9300	2.9200	2.9099	2.8999	2.8900	2.8800	2.8702
0.31	3.0669	3.0560	3.0452	3.0344	3.0236	3.0130	3.0025	2.9920	2.9810	2.9710
0.30	3.1798	3.1682	3.1567	3.1452	3.1338	3.1225	3.1112	3.1000	3.1000	3.0778
0.29	3.3002	3.2877	3.2756	3.2633	3.2511	3.2390	3.2271	3.2151	3.2151	3.1915
0.28	3.4287	3.4154	3.4022	3.3892	3.3764	3.3633	3.3506	3.3377	3.3377	3.3126
0.27	3.5662	3.5520	3.5379	3.5239	3.5100	3.4962	3.4826	3.4688	3.4553	3.4419
0.26	3.7139	3.6996	3.6835	3.6685	3.6535	3.6387	3.6240	3.6095	3.5959	3.5805
0.25	3.8730	3.8566	3.8403	3.8241	3.8079	3.7919	3.7759	3.7604	3.7448	3.7292
0.24	4.0450	4.0272	4.0094	3.9919	3.8747	3.9573	3.9401	3.9232	3.9066	3.8898
0.23	4.2313	4.2120	4.1928	4.1737	4.1549	4.1362	4.1177	4.0993	4.0811	4.0630
0.22	4.2342	4.4130	4.3921	4.3715	4.3509	4.3305	4.3103	4.2903	4.2705	4.2505
0.21	4.6558	4.6327	4.6098	4.5871	4.5647	4.5425	4.5204	4.4983	4.4768	4.4556
0.20	4.8980	4.8736	4.8484	4.8236	4.7990	4.7746	4.7503	4.7253	4.7026	4.6791

TABLE 3-B

VALUE OF COS θ (POWER FACTOR) FOR $\frac{W_1}{W_2}$ OR $\frac{S_2}{S_1}$

$\frac{W_1}{W_2}$	Cos θ	$\frac{W_1}{W_2}$	Cos θ	$\frac{W_1}{W_2}$	Cos θ	$\frac{W_1}{W_2}$	Cos θ	$\frac{W_1}{W_2}$	Cos θ
$\frac{W_1}{W_2}$ or $\frac{S_2}{S_1}$ Positive									
0.847	0.99	0.554	0.89	0.381	0.79	0.246	0.69	0.117	0.59
0.790	0.98	0.525	0.88	0.367	0.78	0.233	0.68	0.104	0.58
0.747	0.97	0.507	0.87	0.353	0.77	0.220	0.67	0.092	0.57
0.712	0.96	0.490	0.86	0.339	0.76	0.207	0.66	0.079	0.56
0.681	0.95	0.473	0.85	0.325	0.75	0.193	0.65	0.066	0.55
0.654	0.94	0.457	0.84	0.312	0.74	0.181	0.64	0.053	0.54
0.629	0.93	0.441	0.83	0.298	0.73	0.168	0.63	0.039	0.53
0.605	0.92	0.425	0.82	0.285	0.72	0.156	0.62	0.026	0.52
0.583	0.91	0.410	0.81	0.272	0.71	0.143	0.61	0.013	0.51
0.563	0.90	0.396	0.80	0.259	0.70	0.130	0.60	0.000	0.50
$\frac{W_1}{W_2}$ or $\frac{S_2}{S_1}$ Negative									
0.013	0.49	0.154	0.39	0.312	0.29	0.498	0.19	0.729	0.09
0.027	0.48	0.169	0.38	0.329	0.28	0.519	0.18	0.756	0.08
0.041	0.47	0.183	0.37	0.346	0.27	0.540	0.17	0.784	0.07
0.054	0.46	0.199	0.36	0.364	0.26	0.562	0.16	0.811	0.06
0.068	0.45	0.214	0.35	0.382	0.25	0.584	0.15	0.840	0.05
0.082	0.44	0.230	0.34	0.400	0.24	0.606	0.14	0.870	0.04
0.096	0.43	0.246	0.33	0.419	0.23	0.630	0.13	0.902	0.03
0.110	0.42	0.262	0.32	0.438	0.22	0.654	0.12	0.933	0.02
0.125	0.41	0.279	0.31	0.458	0.21	0.678	0.11	0.967	0.01
0.139	0.40	0.295	0.30	0.478	0.20	0.703	0.10	1.000	0.00

If the meter had run backwards during the time, and $S_1 = 154.5$ seconds, then

$$\frac{S_2}{S_1} = \frac{52.7}{-154.5} = -0.341$$

cos θ corresponding to $\frac{S_2}{S_1} = -0.341$ is 0.27

MEASUREMENT OF KVA AND KVARS (REACTIVE KVA)

The volt-amperes of an alternating-current circuit are the product of the effective values of the current and voltage, regardless of the phase angle between them. As mentioned previously, they may be determined from measurements with voltmeters and ammeters. The power in watts is the product of the current and voltage and the cosine of the angle between them, and may be measured with a wattmeter. Reactive power is measured in vars, or in multiple units, as kilovars or megavars. The vars are the product of the current and voltage and the sine of the angle between them. From analogy to watts, the vars may be determined from the following equations:

for a single-phase circuit

$$\text{vars} = EI \sin \theta$$

for a two-phase circuit

$$\text{vars} = \sqrt{2}\, EI \sin \theta$$

for a three-phase circuit

$$\text{vars} = \sqrt{3}\, EI \sin \theta$$

where E is the line voltage, I the line current and θ the power factor angle.

The relation between kilowatts, kilovars and kilovolt-amperes is shown in

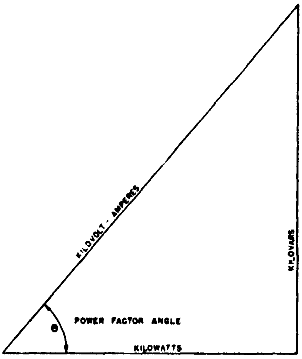


Fig. 3-26. Relation of Kilowatts, Kilovolt-amperes and Kilovars in an A-C Circuit

Fig. 3-26. From this diagram it will be seen that vars may be determined from measurements of power (kw), using wattmeters, and measurements of kva, using ammeters and voltmeters. The following equation applies:

$$\text{kvar} = \sqrt{(\text{kva})^2 - (\text{kw})^2}$$

Kvar Measurement

Kvar hours can be measured by a watthour meter, the potential circuits of which are energized by voltages in quadrature to or displaced 90 electrical degrees from the normal exciting voltages that would be used for watthour metering. The following are the methods usually adopted to accomplish this:

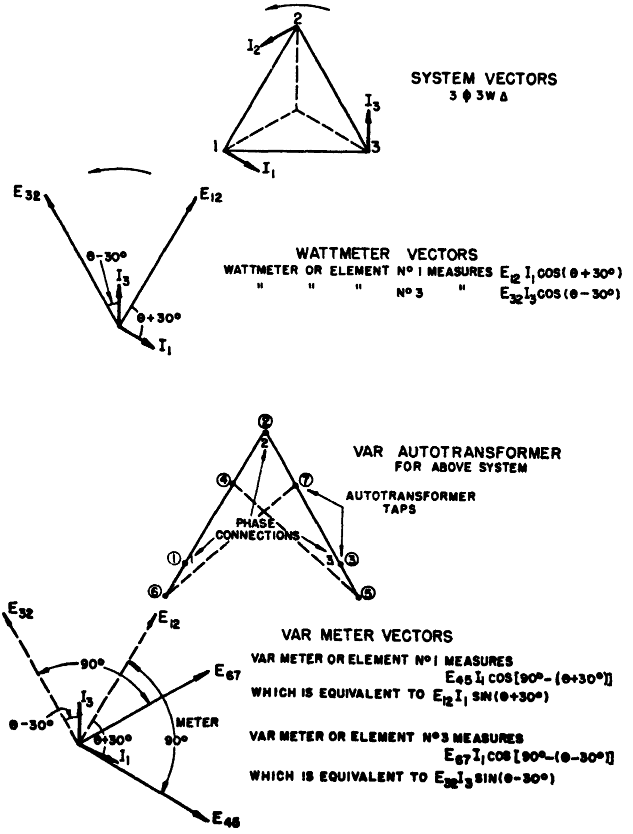

SYSTEM VECTORS
3 ϕ 3W Δ
2
1
3
I_1
I_2
I_3
E_{32}
E_{12}
$\theta - 30°$
$\theta + 30°$
WATTMETER VECTORS
WATTMETER OR ELEMENT N° 1 MEASURES $E_{12} I_1 \cos(\theta + 30°)$
" " " N° 3 " $E_{32} I_3 \cos(\theta - 30°)$
VAR AUTOTRANSFORMER
FOR ABOVE SYSTEM
AUTOTRANSFORMER TAPS
PHASE CONNECTIONS
②
④
⑦
①
③
⑥
⑤
VAR METER VECTORS
VAR METER OR ELEMENT N° 1 MEASURES
$E_{45} I_1 \cos[90° - (\theta + 30°)]$
WHICH IS EQUIVALENT TO $E_{12} I_1 \sin(\theta + 30°)$
VAR METER OR ELEMENT N° 3 MEASURES
$E_{67} I_1 \cos[90° - (\theta - 30°)]$
WHICH IS EQUIVALENT TO $E_{32} I_3 \sin(\theta - 30°)$
E_{67}
E_{45}
90°
METER
90°

Fig. 3-27. Vector Diagrams for Measurement of Active and Reactive Components of Power or Energy in a 3-Phase, 3-Wire Delta Circuit with Lagging Power Factor

Single-Phase Circuits: A standard single-phase watthour meter is generally used, the potential circuit of which is arranged with a combination of resistance and capacitance in series with the usual potential coil of the meter. With such an arrangement, the potential flux for the varhour meter leads by 90° that of the watthour meter, and by a simple reversal of potential connections the meter rotates forward for lagging power factor. The accuracy of this method is affected by frequency and temperature changes. A change in frequency from 60 to 59 or 61 cycles may affect the over-all accuracy of the meter as much as several per cent; the ambient temperature error may amount to 2 per cent for a 25 C change in temperature. Connections are shown in Fig. 7-28.

Two-Phase Circuits: The measurement of the kvars is easily obtained because of the nature of the circuit. Since the potentials of the two phases are normally in a 90° voltage relation, the desired results can be obtained by causing the current from each phase to react with the potential from the other phase. The voltages are assumed to be equal in magnitude, that is, balanced. This method is applicable to any two-phase, three- or four-wire circuits as in Figs. 7-36 and 7-37.

Three-Phase Circuits: For a circuit of this type, the 90° shift in potential

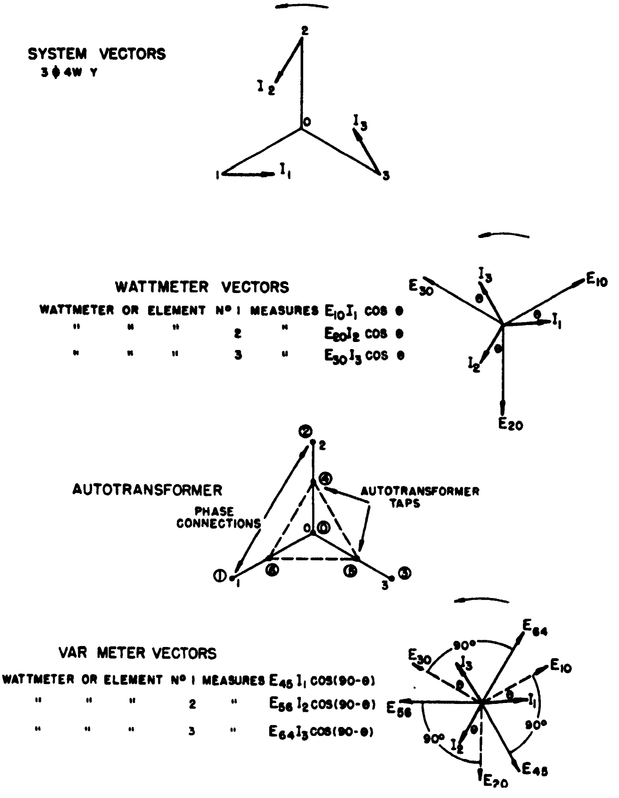


Fig. 3-28. Vector Diagrams for Measurement of Active and Reactive Components of Power or Energy in a 3-Phase, 4-Wire Wye Circuit with Lagging Power Factor

is usually obtained by means of autotransformers combined to form what is known as a "phasing transformer" or "reactive component compensator." (Figs. 3-27, 3-28 and 3-29.) These autotransformers perform the double function of shifting the voltage of each element 90° in phase position and of supplying a voltage to each element equal in value to the line voltage, thus permitting the use of a standard watthour meter. Figs. 7-29 and 7-32 show typical connections.

Figs. 3-30 and 3-31 show typical arrangements for autotransformers suitable for both kvarh and kvah measurements on three-phase three-wire and three-phase four-wire two-element meters. Figs. 7-39, 7-40 and 7-41 show standardized terminal markings and arrangements for phase-shifting devices used in metering.

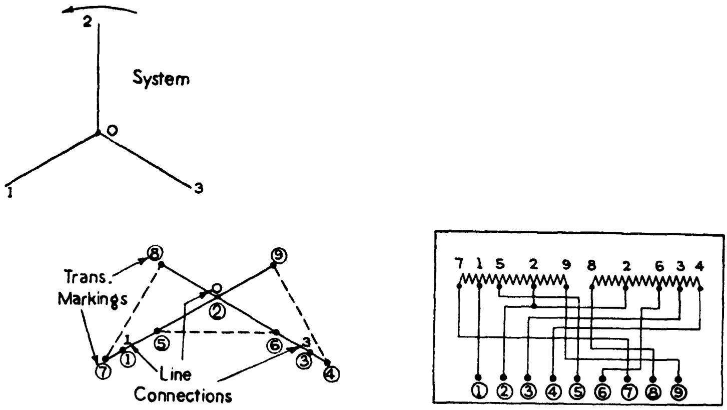


Fig. 3-29. Vector Diagrams and Internal Connections of Autotransformer of Another Arrangement for 3-Phase, 4-Wire Wye Circuits

The necessary quadrature potential may be obtained also by "cross-phasing," that is, by causing each current element of the meter to react with the voltage between the two line wires other than that in which it is connected. Where this is done without the use of autotransformers, the potential is 1.732 times the required value and the meter reading must be corrected by applying a constant of 0.577, or by using a special register gearing.

The accuracy of all methods of measuring polyphase reactive kilovolt-amperes by the use of autotransformers, or "cross-phasing," depends upon balanced line voltages. In general, line voltages are sufficiently balanced to give satisfactory results for commercial measurements.

Kva Measurement

There are a number of methods of obtaining kilovolt-ampere-hours or kilovolt-ampere demand. The following are considered practical:

1. Meters that measure true kva irrespective of power factor, lagging or leading (meters using the ball-type mechanism, Fig. 16-23).
2. Use of a watthour and a varhour meter to record kw demands and kvar demands from which the kva demand is determined by calculation. Fig. 3-31.
3. A "displaced-voltage" (lagged potential) meter. Figs. 3-30 and 3-31.
4. Meters in which the kw and kvar demands are recorded at right angles to each other on the same chart. The hypotenuse of the tri-

angle thus formed is a measure of kva demand.

5. The Trivector and the Metrovick meters. While these are commercially available, they are not used extensively in this country.

The meters mentioned under (1) consist essentially of a watthour meter and a varhour meter mechanically interlinked with a ball mechanism so that the instantaneous values of the reactive and energy components are added vectorially. They give true measurements of kva and total kvah directly. Meters of this type, with their function, are described in Section 16.

The measurement of kva-hours by the third method utilizes for its operation a watthour meter in which the effective potential flux has been displaced by an angle corresponding to the average power factor of the load being metered; thus the phase angle between the voltage and current is practically eliminated and the speed of the meter will be proportional to the kva over a limited range of power factor. This may be accomplished either by displacing the phase relation of the voltage applied to the meter by an autotransformer, or by means similar to the method used in the lag adjustment. The registration will be true volt-ampere-hours only at an assumed power factor. However, the accuracy will be satisfactory for most commercial measurements over an appreciable range of power factor. By calibrating the meter 1 per cent fast as a watthour meter, the error due to phase displacement will be no greater than ± 1 per cent over a specified range, and on that basis the power factor ranges for the listed mean power factor settings are shown in Table 3-C.

It is also possible to determine kilo-

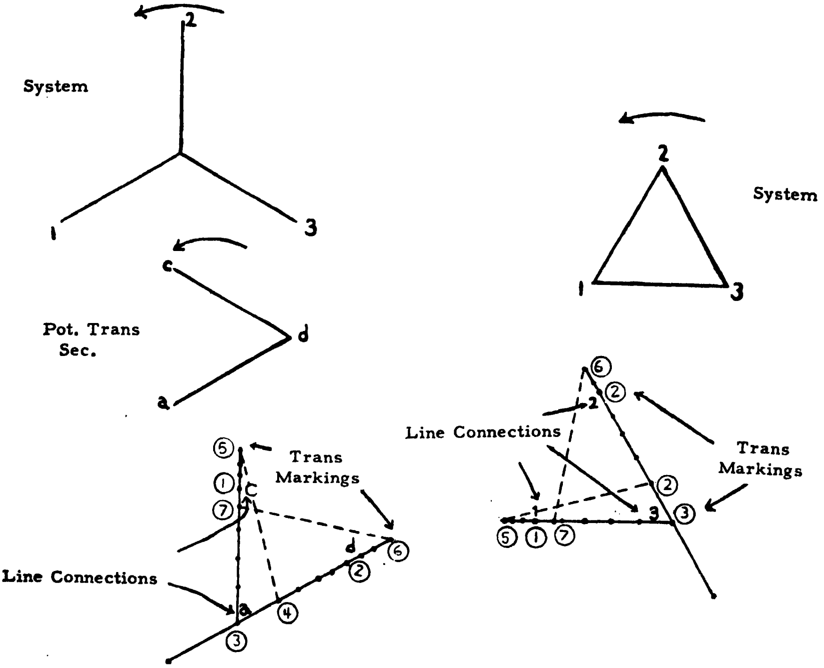


Fig. 3-30. Vector Diagrams of Autotransformer for Kvarh and Kvah Measurements on 3-Phase, 3-Wire and 3-Phase, 4-Wire Wye Circuits. Vector Relations Shown for only One Power Factor Tap (0.82)

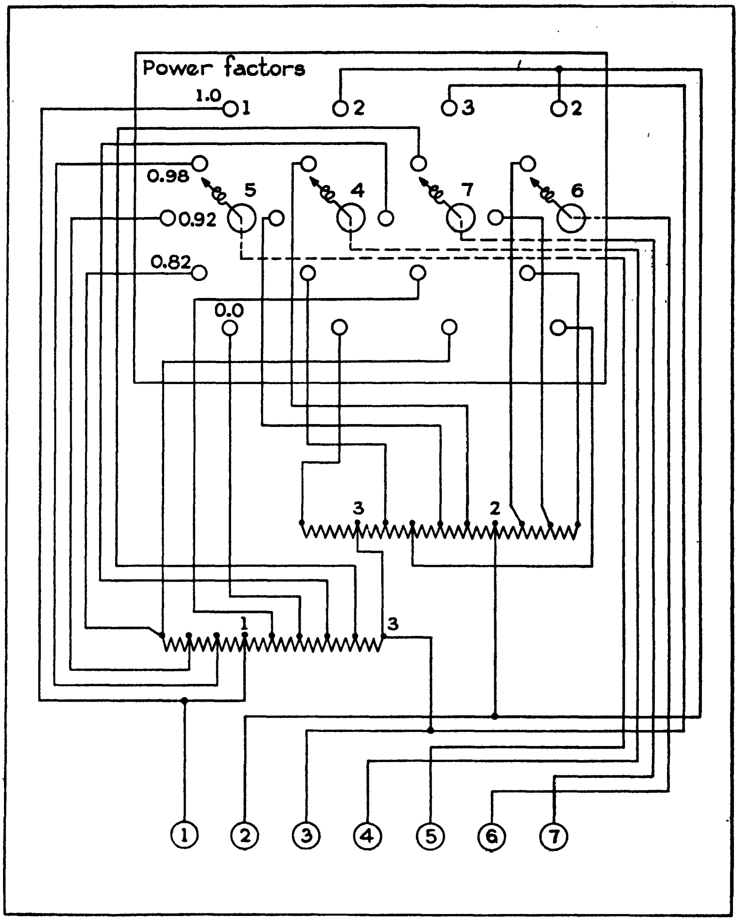


Fig. 3-31. Internal Connections of Autotransformer for Kvarh and Kvah Measurements

TABLE 3-C
RANGE OF MEASUREMENT OF KVA METER BY THE DISPLACED-VOLTAGE METHOD

Mean P. F.	P. F. Range	Mean P. F.	P. F. Range
0.98	1.00–0.98	0.80	0.90–0.66
0.92	0.98–0.82	0.73	0.85–0.58
0.87	0.95–0.75	0.71	0.83–0.55
0.82	0.92–0.69	0.50	0.66–0.32

volt-ampere-hours graphically from measurements of kilowatthours and kilovar-hours. To perform this operation the two quantities are drawn to the same scale, one on the horizontal coordinate and the other on the vertical coordinate. The triangle may then be completed and the length of the hypotenuse will indicate the kilovolt-ampere-hours. It should be noted that this method will not give true kilovolt-ampere-hours unless the power factor is constant. This is illustrated in Fig. 3-32.

Assume that, for a short period of time, the load triangle is as shown in the small triangle A, in which the kilovolt-ampere-hours are as shown by the line a. In the next time interval these values are represented by the triangle B and the line b respectively. During the next interval, the power factor is unity, and the kilovolt-ampere-hours are the same as the kilowatthours as represented by the line c. It is obvious that the total kilovolt-ampere hours are the sum of a + b + c + d + e + f. The sum of the reactive components is represented by the line YG, and of the kilowatthour components by the line OY. The kilovolt-ampere-hours obtained from these two are represented by the line OG, which is less than the sum of a to f inclusive. Since this method is used principally for demand purposes, and since the demand interval rarely exceeds 30 minutes, the power factor will usually be sufficiently uniform to make the difference between the two methods negligible.

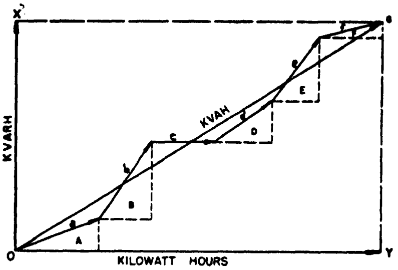


Fig. 3-32. Diagram Illustrating that the Average Kilovolt-amperes Obtained from the Reading of a Watthour Meter and a Varhour Meter is Not Necessarily Correct

The cases mentioned above in which the watthour meter and varhour meter are mechanically interlinked to perform the vector addition are also subject to the conditions just described, unless the combination integrates the instantaneous values of volt-amperes.

Ampere demand meters may also be used for the measurement of kva demand by applying to the readings a multiplying factor equivalent to the line voltage.

SECTION 4

PRINCIPLES OF DEMAND METERS

Early in the history of the electrical industry it became evident that users of electricity, requiring relatively large amounts of power for comparatively short intervals of time, should be assessed an equitable portion of the costs of supplying such short time requirements. The measurement of this assessment, known as the demand charge, led to the development of devices known as demand meters. Such meters register the rate of using power for some chosen interval such as 5, 15, 30 or 60 minutes.

The amount of assessment and the period on which it is based depend on many complicated factors, the discussion of which is beyond the scope of this text.

The need to measure demand has led to the invention of many ingenious mechanisms. The basic principles of the more modern types will be discussed briefly in the following text.

CLASSIFICATION OF DEMAND METERS

Demand meters may be divided into three general classes differing in the means by which the demand is measured.

- Class 1—Curve Drawing Meters
- Class 2—Integrated-demand Meters
- Class 3—Lagged-demand Meters

While some integrating and lagged types of demand meters give a record of their measurement by means of a continuous curve or a series of curves, Class 1 instruments, for the purpose of this section, will be considered as those operating on the electrodynamometer and D'Arsonval principles to distinguish them from the integrating type.

Class 1—Curve Drawing Meters

The electrodynamometer type of demand meter shown schematically in Fig. 4-1 is composed of two independent circuits. The series circuit, carrying the load current or a portion of it, is made up of a few turns of heavy conductor wound on a circular bobbin or frame and fixed to the frame of the instrument. The shunt or voltage circuit is comprised of a relatively large number of turns of fine wire wound to be self-supporting and mounted on a shaft or spindle concentric with the series coils but free to turn through a definite arc. The spindle or shaft which carries the shunt coils, also carries a pen or other marking device, which records its movement on a suitable chart.

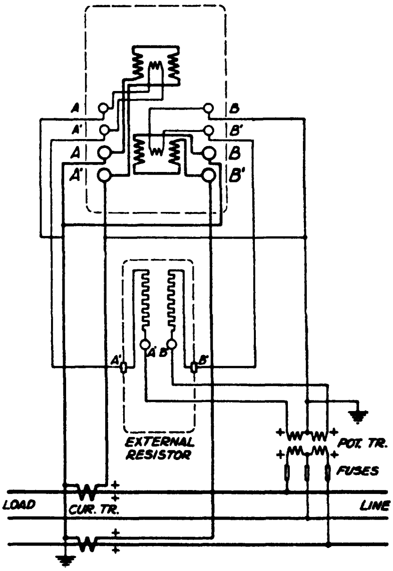


Fig. 4-1. Two Element A-C Wattmeter on 3-Phase, 3-Wire Circuit

The connections to the series and shunt coils are of such instantaneous polarity that the two coils, one fixed and one movable, tend to repulse each other when carrying the circuit quantities. Since the series coils are fixed, this repulsion force causes the movable shunt coils to rotate, carrying the spindle and marking device along with it. This turning movement is opposed by a spiral spring, which allows movement of the spindle until the spring torque and the repulsion torque are equal.

The time factor of such meters is usually provided by either a mechanical clock escapement or a synchronous motor. The clock or motor, through suitable gearing, drives at a constant rate of speed a paper roll or chart having time and quantity divisions appropriate to the instrument.

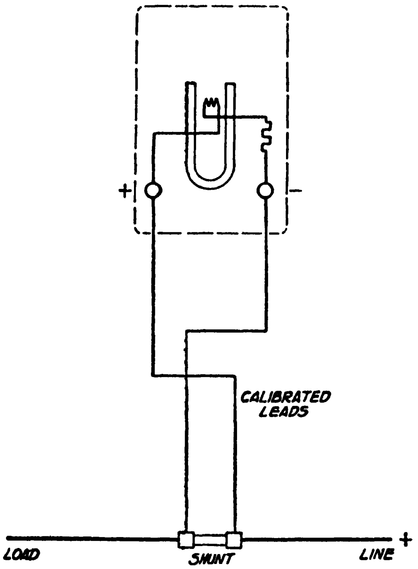


Fig. 4-2. Connections of D'Arsonval Millivoltmeter and Shunt on D-C Circuit

The D'Arsonval principle shown schematically in Fig. 4-2 is, in general, confined to the demand measurement of direct current amperes and differs from the electrodynamometer type principally in the means used to obtain the deflecting torque. The moving coils carry only a very small part of the load current, and the instrument is commonly referred to as a shunted ammeter or millivoltmeter. The moving element, consisting of a relatively large number of turns of fine wire wound on an aluminum bobbin or frame, is supported on jeweled bearings between the poles of the permanent magnet. Within this bobbin or frame is placed a soft iron pole piece which serves to confine the lines of force of the permanent magnets within a certain configuration within the air gap. The polarity of the moving coil windings is such that the torque produced, when the moving coil carries current, moves the coil and its attached pen or other marking device over a suitable chart. Timing is obtained in the same manner as with the electrodynamometer type of instrument.

Curve drawing meters employing electrodynamometer elements may record the instantaneous values of power, reactive power, kilovolt-amperes or amperes, and may be used as demand meters. However, billing tariffs usually specify that the rate of using power be averaged for some definite interval of time. The use of curve drawing instruments under these conditions becomes inconvenient as it is necessary to determine the average value of the power curve for the specified demand interval. Demand meters of this class are not generally used as billing demand meters.

Class 2—Integrated-demand Meters

Mechanical demand measuring devices may be divided into two general categories, indicating or recording mechanical demand meters constructed integral with a watthour meter assembly, and separate mechanical indicating or recording demand meters.

Demand meters of the first category are usually composed of two basic elements, the kilowatthour meter and the demand registering, indicating or recording mechanism.

The action of one of these arrangements under conditions of load is as follows and is illustrated in Fig. 4-3. The rotation of the watthour meter disk is transmitted through suitable gearing to the energy integrating dials of the kilowatthour meter. This same motion, through a different set of gears, causes a pointer, pen, stylus, or

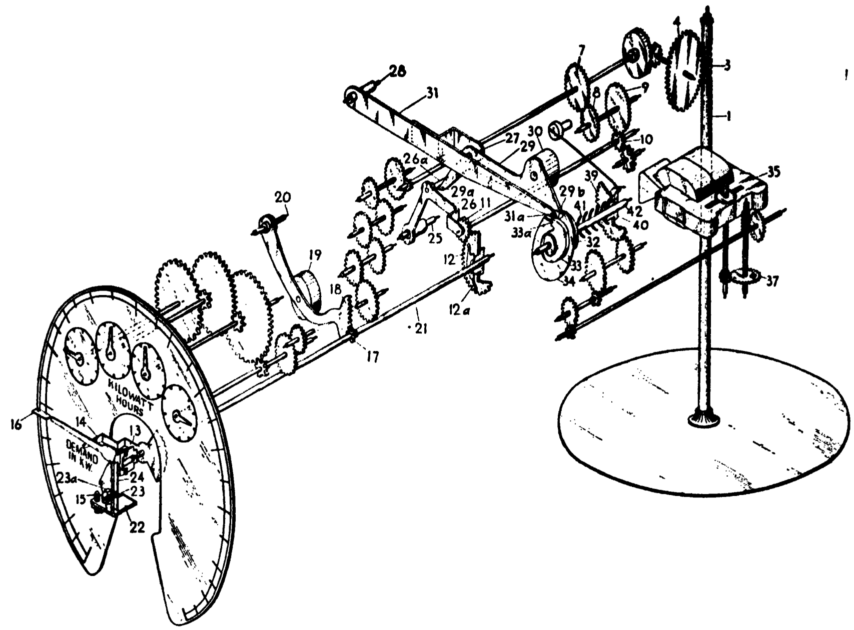


Fig. 4-3. Schematic Diagram of Indicating Watthour Demand Register

pusher member, whichever the case may be, to move through the arc of a circle. The arc of this circle, which may be from seventy to three hundred degrees, is marked in appropriate units, either kilowatts or an arbitrary number. As the pointer or pusher member moves up the scale it carries with it a pointer or other indicator. At the end of the specified demand interval, determined by the design of the device, the timing element, which may be a small synchronous motor or a mechanical clock, releases the pusher element from the disk-driven gear train assembly, allowing it to return to the zero position under the action of a spring, weight, or motor driven mechanism, where it again engages with the meter disk driven gears and repeats the cycle. When the timing device releases the pusher assembly from the disk driven gear train, the maximum demand pointer or indicator remains at the highest scale reading to which it has been driven during the time it was in contact with the pusher element. It is held in this position by a friction device which, as usually constructed, can only be released to move the pointer to zero when actuated by a reset device manually operated from outside the case.

Between resets any movement of the pusher assembly which is greater than the highest preceding movement, advances the demand pointer or indicator to a new and higher reading on the scale. It remains at its maximum position until reset manually to zero.

Since the movement of the pointer and pusher element over the scale depends on the speed of rotation of the watthour meter disk, which in turn is proportional to the power flowing in the circuit, the rate of movement of the pointer or pusher over the scale is directly proportional at every instant to the rate of using energy or to the demand. Fig. 4-4 is a graph showing the response characteristics of a mechanical demand register for a steady load for a 15-minute demand interval register.

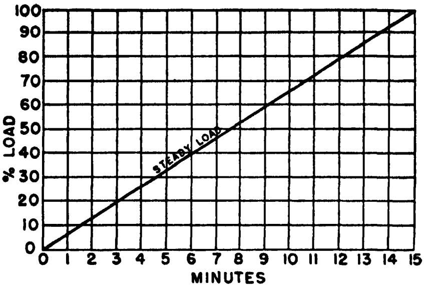


Fig. 4-4. Response Characteristic of 15-Minute Integrating-Demand Register

In some constructions of the above device the pointer or indicator moving over a scale is replaced by an inking stylus which traces the travel of the pusher element on a suitably divided chart.

In addition to the timing mechanism, which resets the driver element to zero at the end of the demand interval, a second electric motor or spring driven mechanism advances the chart a definite amount either at the instant of resetting or immediately before or after, depending on the type.

It should be noted that the mechanical type of demand register or indicator can also be used to measure kilovar demand or kilovolt-ampere demand by connection of the watthour meter potential circuits to appropriate phase changing voltage autotransformers.

In one type of recording kva demand meter a unique method is used to obtain the kilowatt demand and kilovolt-ampere demand, as well as instantaneous power factor and integrated kilovar-hours, kilovolt-ampere-hours and kilowatthours on the same instrument.

The values of kilovolt-ampere demand and instantaneous power factor are obtained by mechanical vector addition of active and reactive components of the power by mechanical solution of the equation $va = \sqrt{w^2 + var^2}$.

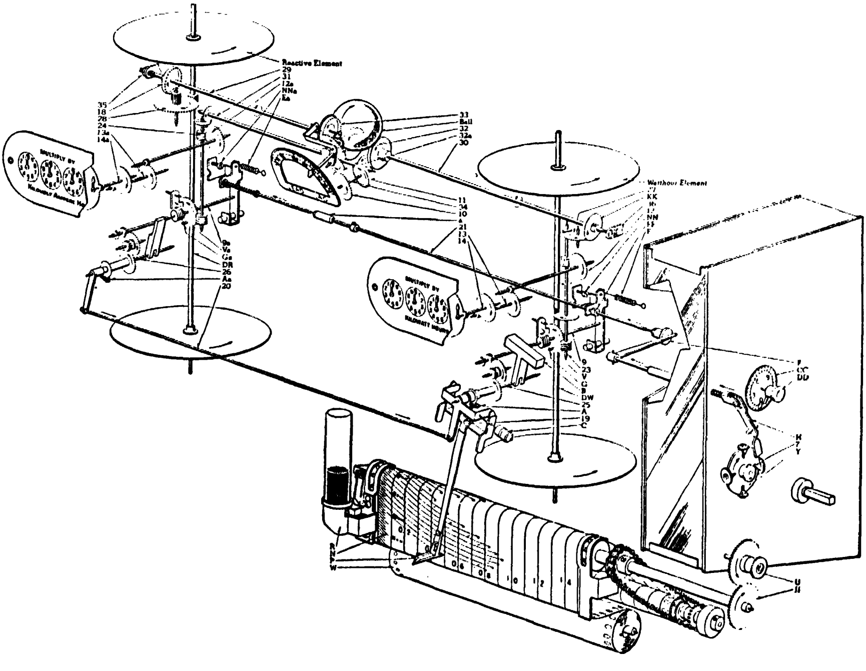


Fig. 4-5. Schematic Diagram of Kilovolt-ampere Demand Meter

Reference to Fig. 4-5 and the following text demonstrates the operating principle of the device.

The meter consists of two watthour meter elements with a separate reactive compensator (autotransformer) provided in order that one set of the watthour meter elements of the combination can be connected to measure kilovar-hours. It contains a ball mechanism by means of which the active and reactive components of the load are added vectorially. A suitable chart mechanism records the kw and kva demands. There is a register for kilowatthours, a similar register for kilovolt-ampere-hours and, in more recent construction, a register for kilovar-hours.

Since sine squared plus cosine squared is equal to one, it is readily shown that volts times amperes is equal to the square root of the sum of the squares of the watt and wattless components, or $va = \sqrt{w^2 + var^2}$. The ball mechanism in the meter makes this vector addition in the following manner; the ball, Fig. 4-6, which is driven by the two disks d_1 and d_2, in turn drives wheel *w*.

The condition corresponding to Fig. 4-6 is obtained at 70.7% power factor, at which time the current in a polyphase circuit lags behind the voltage by an angle of 45 degrees. Under these conditions the watthour meter and varhour meter speeds are exactly equal. Under these assumed conditions, it is evident that the ball will rotate about the horizontal axis *xy*. If the radii *a* and *b* are drawn from the point of contact with the disks d_1 and d_2, perpendicular to *xy*, the lengths *a* and *b* will be proportional to the watthour and varhour meter speeds. The wheel *w* rotates at a speed proportional to the radius of the sphere, which is somewhat greater than *a* and *b*. It is evident that the two triangles *a b c* are equal for the assumed load power factor conditions and it can be proven that they are equal for all power factors. Since *a b c* is a right triangle, *c*, the radius of the sphere, is equal to the square root of a^2 plus b^2 and therefore a true vector addition.

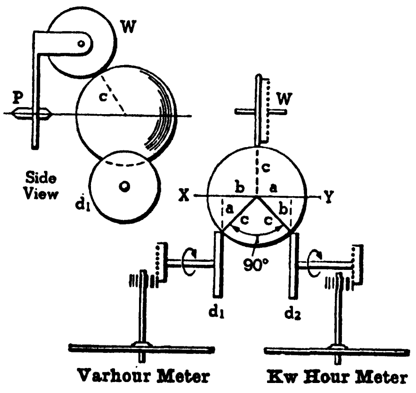


Fig. 4-6. Varhour Diagram of Ball Mechanism at 70.7% Lagging Power Factor

The angular motion of the wheel *w* is equal to the vector sum of the motions of the watthour and varhour elements and is equivalent to kilovolt-ampere-hours. The wheel *w* is mounted in a frame which moves about an axis perpendicular to the plane in which *x y* moves and the axis of the frame would, if extended, pass through the center of the ball. As the axis of rotation of the ball shifts, the position of *w* changes so that it always revolves on a circle at right angles to *x y* with a speed proportional to the radius *c*. Through suitable gearing, the wheel *w* is connected so as to drive the left-hand dial on the meter which then registers kilovolt-ampere-hours.

The pen is removed from the left-hand mechanism and is replaced by a short arm which through a connecting rod (20) drives the pen *p* (Fig. 4-5) on the right-hand element. The right-hand register is connected to the watthour meter in the usual manner, but instead of driving the pen, the demand mechanism carries a small adjustable stop which moves about the same center as the pen driven from the kva mechanism but follows the pen due to the fact that kilowatts are always equal to, or less than, kilovolt-amperes. At the end of the demand interval when the built-in clock (not shown) begins the reset cycle the pen makes a hook mark at the maximum kva travel. The pen is then released to fall back against the kilowatt stop

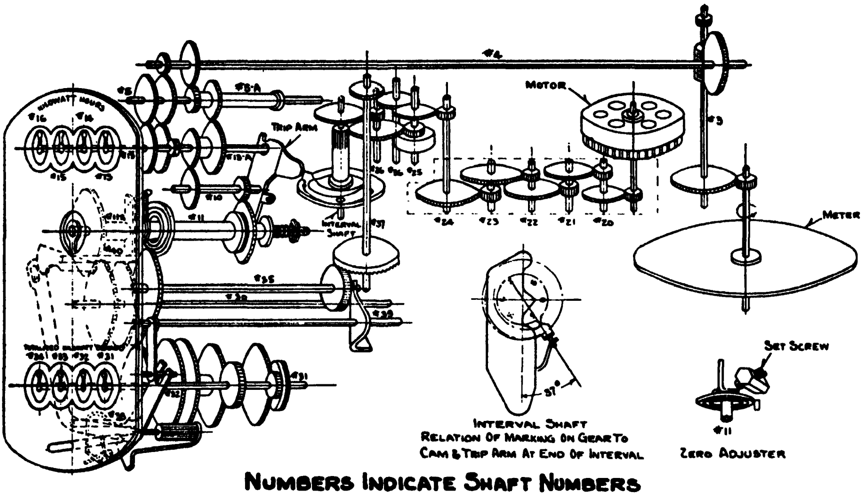


Fig. 4-7. Cumulative Demand Register With Dials and Pointers

where it makes a second hook mark on the chart. An instant later the pen carriage is released a second time to return to zero. The record on the chart then gives both kilowatt and kilovolt-ampere demand and by simple calculation or reference to a prepared chart, average power factor for the interval may be determined. Instantaneous power factor can also be determined at any time by reference to a pointer carried by the carriage of wheel *w*, moving over a scale.

Cumulative Register—This type of demand register does not have a sweep hand. Instead it has an additional set of dials and pointers, similar in appearance to the watthour dials of a watthour meter register, Fig. 4-7. In a variation of this arrangement the pointers are stationary, and the dials rotate, Fig. 4-8.

While the basic principle of operation of the cumulative register is the same as the sweep hand type of register, the resetting operation and manner of obtaining readings are different. Instead of the disk-driven pusher element of the sweep hand type of dial, the pusher element of the cumulative register causes a set of gears to transmit this motion to a set of stop pins, which assume a position corresponding to the maximum demand. These stop pins remain in the maximum position to which they have been driven by the pusher element, when the timing element releases the pusher element to return to zero at the end of the demand interval. In order to determine the maximum demand reading, it is necessary to operate a reset device which causes a set of pointers or indicators to assume a position corresponding to the position of the pusher element driven stop pins. This reading remains on the dials or indicators until the mechanism is again reset to zero and thereby preserves a record of the billing quantities until the reading operation is again performed.

Following is a brief description of the operation of one type of cumulative demand register.

The register, Fig. 4-8, has a pointer pusher (14) that is geared to the watthour meter shaft. In this train of gears is a clutch (9) that will permit the pointer pusher to be brought back to its zero position. The demand pointer mechanism and pointer (16 to 22) are not rigidly attached to the pointer pusher and are therefore held at the highest point to which they have been carried by a friction pad (18).

During each demand interval the pointer pusher is driven forward at a rate proportional to the load on the meter. If it has not previously been carried to a higher point during the previous interval, the demand pointer is pushed forward. At the end of each demand interval the pointer pusher is returned to its zero position by the interval resetting device. The resetting operation which must be performed at the end of each reading period is semi-automatic. The arm attached to the meter cover is unsealed, turned up and then depressed. This action causes the knob and pointer assembly (38) at the bottom center of the register to be pushed inward slightly. Through the motion of a shaft (39) attached to the knob, the demand pointer mechanism is engaged through a clutch (45) with the train of gears to the cumulative demand dials. Simultaneously, the register timing motor is engaged, first through gear to gear (through 41 to 40) and next through pin to pin (through 43 to 44). The motor then turns the demand pointer mechanism and pointer back to zero. The cumulative demand dials move forward proportionally after which the cumulative dials automatically disengage from the demand pointer mechanism and the register timing motor disengages from both.

There will, of course, be some variation in operating and resetting functions between cumulative registers of different manufacture. However, the foregoing exposition is basically the same for all registers of this general type.

Cumulative types of demand meters in which the demand record is preserved on a chart have been developed but at this time are not generally available for commercial use.

Class 2 demand meters of the second category are usually separate devices operated from electrical contacts mounted on the measuring device. This measuring device is usually a kilowatthour meter which may, by proper connection of the potential circuits, measure kilowatthours, kilovar-hours or kilovolt-ampere-hours, and by use of electrical contacts mounted thereon, deliver electrical impulses having values in the above units.

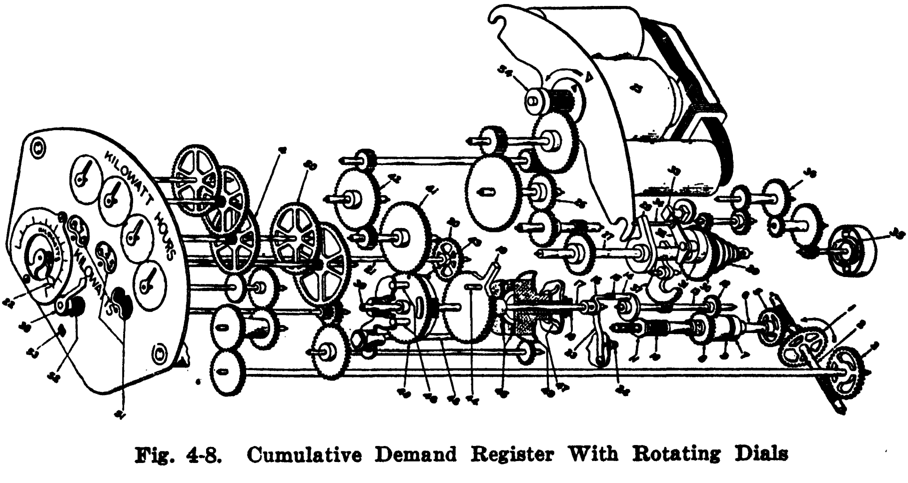


Fig. 4-8. Cumulative Demand Register With Rotating Dials

The contact mechanism, Fig. 4-9, is mounted on either the frame of the watthour meter or on the register back plate. It is usually composed of a first gear wheel which engages either with a special screw worm cut into the watthour meter disk shaft or one of the gear wheels of the watthour meter register. This first gear wheel drives a set of cams either directly or through appropriate gearing. These cams may have points ranging from one to twenty in number.

A phosphor bronze spring member bearing a contact point of special metal rides on the cams. As the cams are caused to turn by rotation of the meter disk shaft, the cam points cause the contacts to alternately open and close and thus produce electrical impulses which can be made available for operation of a demand meter. Since the speed of rotation of the watthour meter shaft is proportional at all times to the quantity being measured, the number of electrical impulses produced by the contact mechanism for any given period of time can be a measure of the rate of flow of the quantity, or, in other words, demand.

From the foregoing brief description of contact devices it can be readily seen that a number of factors can be varied to obtain almost any value per electrical impulse. Manufacturers supply bulletins on contact-operated devices, listing the number of cam points, gear ratios, etc., normally available, and can usually furnish special contacts to meet any requirement. The reader should refer to such bulletins for instruction on the calculation of the constant required for any particular condition, as well as the preferable arrangement of the contact device.

Contact-operated demand meters are usually constructed as separate units whose operation depends on an electromagnetically driven measuring mechanism. Such mechanisms are essentially revolution or electrical impulse counters. In some forms they require a separate timing mechanism, usually a contact-making clock which may be either electrically timed by a

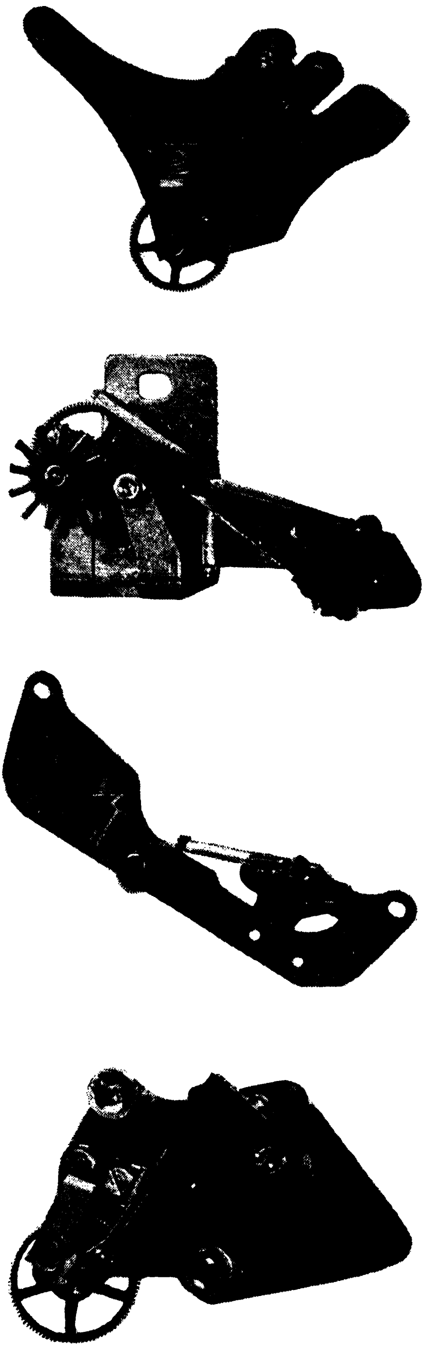


Fig. 4-9. Various Types of Demand Contact Mechanisms

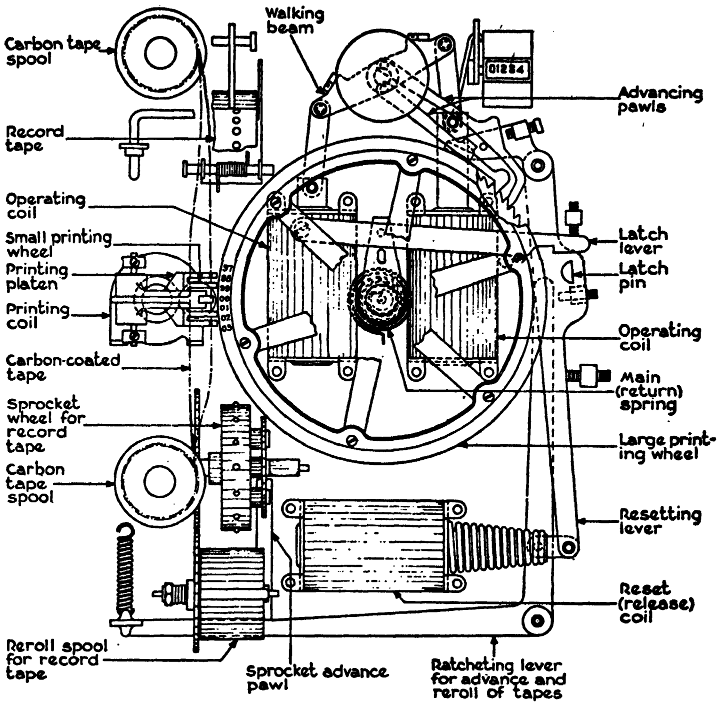


Fig. 4-10. Printing Type of Contact-operated Demand Meter

small synchronous motor or mechanically timed by a mechanical clock escapement which initiates the resetting impulse at some chosen demand interval.

Contact-operated demand meters are available in a number of forms. In one arrangement, Fig. 4-10, the impulses received from the contact device on the watthour meter cause, through an electromagnetically driven notching mechanism, the advance of a type wheel bearing the numbers from 00 to 99 against the force of a coiled spring. As this wheel is advanced beyond the number 99 a trigger arrangement causes a smaller wheel bearing the numbers 0, 1 and 2 to move into line with the first type wheel and provides the first hundreds number. The large type wheel may then be advanced until the count is 199 when the same trigger arrangement advances the small type wheel to the second hundreds position.

The wheel can then be further advanced to a total of 299 impulses beyond which point the wheel cannot be advanced. When the resetting impulse is received from the timing device it causes a light-weight electromagnetically-operated printing pad to strike an inked tape located over a white paper tape in such a manner that the numbers on both the large and small type wheels are printed on the white paper tape thus providing a record of the impulses received from the meter contacts during the demand interval. Simultaneously with the operation of the printing device, separate electromagnets release the dog and pawl arrangement which holds the large type wheel at the advanced position, allowing the type wheels both large and small to return to the zero position. Printing and resetting are accomplished in one operation because of the difference in inertia between the printing platen which is relatively light and the pawl release mechanism which is comparatively heavy.

This demand meter is also provided with a cyclometer counter which accumulates the number of impulses sent by the contact device. By applying the proper constants to the reading of this counter, the impulses registered can be converted into kilowatthours. These units compared to the units registered by the watthour meter provide a ready means of checking the performance of both the contacts and the demand meter.

This demand meter is also provided with a scale and dial which show the highest number of impulses registered on the record tape without inspection of the tape. This dial is usually reset manually to zero at each reading period. A dial similar to the maximum dial also provides a reading of the number of impulses received at any instant between reset periods. As previously noted this device may require a separate timing device to control the reset cycle. However, a form is available which contains a built-in synchronous motor timer and consequently a separate timer is not required. This built-in timing device may also be connected to perform the timing for a second demand meter not having this timing mechanism.

At present, such types of demand meters with integral timers are only available for 15 and 30 minute periods. Fig. 4-11 shows the arrangement of this timing device.

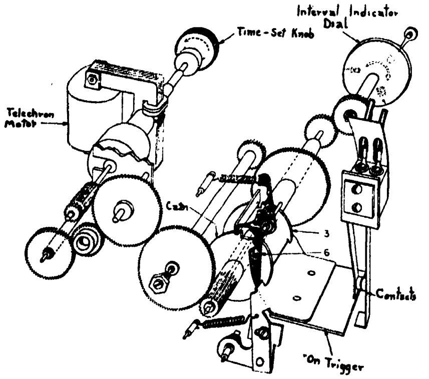


Fig. 4-11. Integral Timing Device of Printing Type Demand Meter

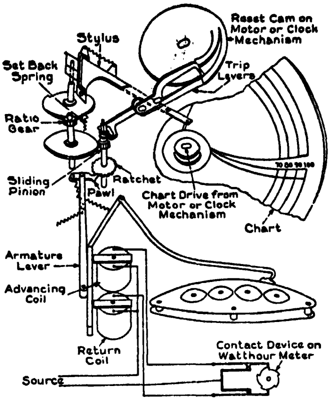


Fig. 4-12. Circular Chart Type of Contact-operated Demand Meter

A second form of impulse-operated demand meter differs from the first in that the impulses received from the contact devices cause a pen arm or stylus to move through an arc over a suitably divided chart. In this form the length of the arc travel is proportional to the demand. This chart may be chosen to read the quantity measured directly or may have an arbitrary scale with which a proper multiplying constant must be used to determine the magnitude of the quantity.

One form of this device is available for the measurement of kva and kw from a single chart. This is accomplished by mounting contact devices on both a kilovarhour meter and a kilowatthour meter. The impulses received from each source at the demand meter are added vectorially to produce an indication of kva demand, by means of the ball mechanism, previously covered in this section.

A special form of this same device allows the totalizing of two circuits on one chart through the proper arrangement of an electromagnetically-operated mechanism.

A third form of contact-operated demand meter employing an electromagnetically-actuated advancing system, differs principally in the manner of recording the measured quantity. In this particular device, shown in Fig. 4-12, the advancing mechanism causes a pointed stylus, mounted on a movable

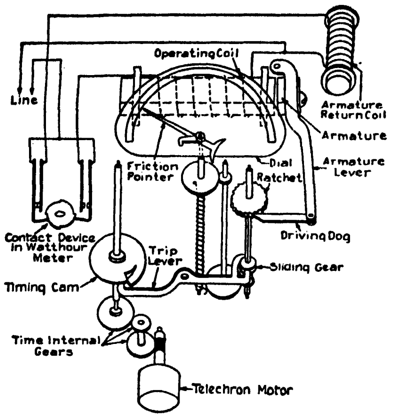


Fig. 4-13. Indicating Type of Contact-operated Demand Meter

member similar to the customary pen arm, to move in an arc over the surface of a wax-coated chart. In moving over this chart the pointed stylus removes the outer wax coating, exposing a black undercoating which appears as a black line on a lighter background. The length of the line, referred to an arbitrary scale, represents the magnitude of the quantity measured. The timing function in a device of this kind is performed by either a mechanical clock mechanism or a synchronous timing motor, either of which may be built into the device.

The timing device moves the circular chart continuously with the result that the record is a series of steps, each step representing an impulse. However, the chart advance is so slight between impulses that the chart record usually appears as a smooth curved arc with no noticeable staggering of the impulses. Charts are normally available for 8, 16 or 32 days and may be obtained having either inside or outside zero. Inside zero charts are usually employed where the normal deflection of the stylus is 50% or more of full scale, since the lines are wider spaced the further they extend from the chart center. This aids in reading the individual demands for any one period. On the other hand, where deflection is 10% to 25% of full scale deflection, the outside zero chart offers some advantages.

This type of meter is also available in duplex form, that is, it can record the total number of impulses received from two separate sources.

An impulse counter dial is usually provided to furnish means of checking the operation of the device against the units measured by the watthour meter driving its actuating contact device.

Fig. 4-13 shows another contact-operated demand meter resembling the demand registers mounted on watthour meters. The basic operating principle, however, of all contact-operated demand meters is much the same, differing only in the linkage between the actuating electromagnets and the registering or recording means.

Contact-operated demand meters lend themselves particularly well to installations where it is necessary to totalize the demands of several circuits. Totalization is usually accomplished by the use of totalizing relays. These devices receive electrical impulses from more than one circuit, totalizing these impulses by mechanical means and transmitting a resultant impulse which is representative of a chosen number of received impulses.

Fig. 4-14 shows the electrical connections of one of these devices. Fig.

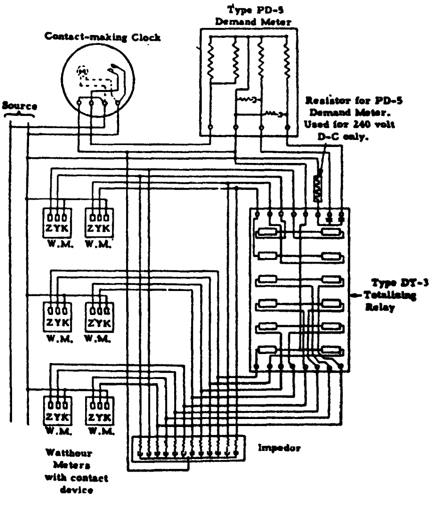

Type PD-5 Demand Meter
Contact-making Clock
Source
Resistor for PD-5 Demand Meter. Used for 240 volt D-C only.
ZYK
W.M.
ZYK
W.M.
ZYK
W.M.
ZYK
W.M.
ZYK
W.M.
ZYK
W.M.
Type DT-3 Totalizing Relay
Impedor
Watthour Meters with contact device

Fig. 4-14. Connections of Six-Circuit Totalizing Relay and Printing Demand Meter

4-15 shows the arrangement of the mechanical linkages between various elements.

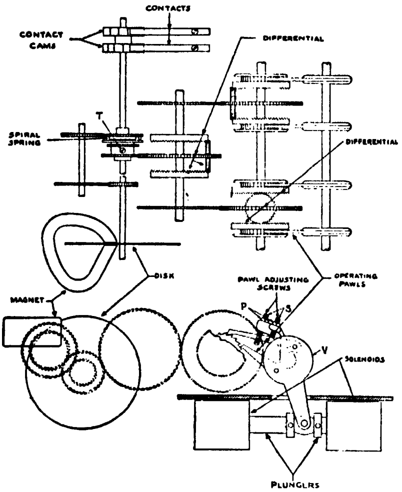


Fig. 4-15. Schematic Diagram of Four-Circuit Totalizing Relay

Devices are available for totalizing two to eight circuits and, by cascading, any number of circuits may be totalized. It must be noted, however, that in any given totalizing scheme, the unit value of all corresponding impulses must be the same. This fact sometimes requires considerable ingenuity in the choice of contact gear ratios, contact points, watthour constants, etc. The applications of such methods of metering are discussed in more detail in Section 6.

Totalizing relays are also available having negative as well as positive elements. The output of such relays represents a difference of two quantities instead of their sum. Such differential devices may be useful in interchange metering problems where a net result is required.

Class 3—Lagged-Demand Meters

Lagged-demand meters may be divided into two general categories; thermal lagged-demand meters and mechanical lagged-demand meters.

The fundamental circuit theory of the thermal wattmeter is quite old, having been developed in Germany many years ago, but was not generally accepted for the measurement of power because of the delayed response which is characteristic of the device. It is interesting to note, however, that this delayed response characteristic was later recognized as a desirable factor in adopting the device for some types of measurements.

The introduction of the thermal meter as an acceptable demand metering device is credited to Mr. P. M. Lincoln who first introduced and manufactured a commercial demand meter in several forms, in Canada. Mr. Lincoln later began the manufacture of the Lincoln thermal meter in the United States and for a number of years it was the only device of its particular construction commercially available for demand measurement.

During the past twenty years other devices, both thermal and mechanical, have been developed having response characteristics similar to the original design. Details concerning the construction and operation of these devices are discussed briefly in this section.

Within the last few years development of power and current measuring devices operating on the thermal principle has received an impetus and at the present time a number of manufacturers can supply thermal electrical measuring devices in various combinations and designs. New developments and applications may be expected in the future as manufacturing research progresses, and new metering requirements occur.

Principle of Operation—Unlike the mechanical demand register, which derives its operating power in part from the watthour meter disk or some external source, the thermal watt demand meter derives its actuating power from the heating effect of the electrical quantity being measured.

At the present time there are two general methods employed by which the heating effect is converted to mechanical motion, the indirect method in which the heat is transferred by convection and the direct method where a bimetallic member is heated as a result of the current flow through it. Fig. 4-16 shows the first arrangement and Fig. 4-17 the second.

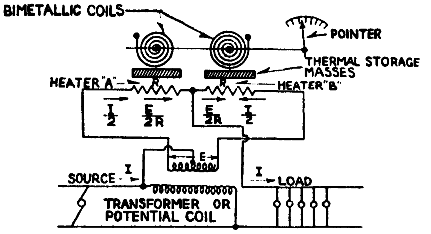


Fig. 4-16. Schematic Circuit Arrangement For Indirectly Heated Thermal Demand Meter

Referring to Fig. 4-16 and 4-17, the following is a brief explanation of the operation of this type of device applied as a single-phase wattmeter on a 2-wire circuit.

The matched bimetallic coiled strips consist of dissimilar metals firmly welded together and having unequal rates of expansion when heated. These are mounted so that they are coiled in opposite directions and oppose one another when expansion of the coils takes place. Strips of resistance material, employed as heaters, are mounted between plates adjacent to the bimetallic coils while, in the directly heated type, the bimetallic coils act as heaters. In Fig. 4-17 a current proportional to line current I_i, together with a current proportional to line voltage I_e are passed through these resistances or heaters, in such a manner that the bimetallic coils are heated to different temperatures, the difference in temperature being proportional to the watts supplied by the source to the loads.

The method of obtaining this difference of temperature is accomplished by the following ingenious circuit arrangements. A potential coil or transformer within the meter has its primary connected across the line and its secondary connected across the two heaters *A* and *B* in series so that when the primary is excited, a secondary current will flow in the heaters, which is proportional to the impressed voltage.

One line wire, carrying the load current in direct connected meters, or a portion of the current in transformer type meters, is connected at the center of the potential transformer secondary in such a manner that the current passes through the two heaters *A* and *B* in parallel, to a junction point between the heaters. An examination of the connections will show that if the resistances of the two heaters, *A* and *B* are equal, one-half the current will flow in each, but in opposite directions.

With this circuit arrangement and directions of current flow, two currents, one proportional to the line voltage and one proportional to one-half the line current, flow in the same direction in one heater, and these two currents flow in opposite directions in the other heater.

In one heater the total current is $I_e + \frac{1}{2}I_i$. In the other heater the total current equals $I_e - \frac{1}{2}I_i$.

Since the heating effect is proportional to the square of the current, or I^2, there will be a heating effect in one heater proportional to $(I_e + \frac{1}{2}I_i)^2$, and in the other heater proportional to $(I_e - \frac{1}{2}I_i)^2$.

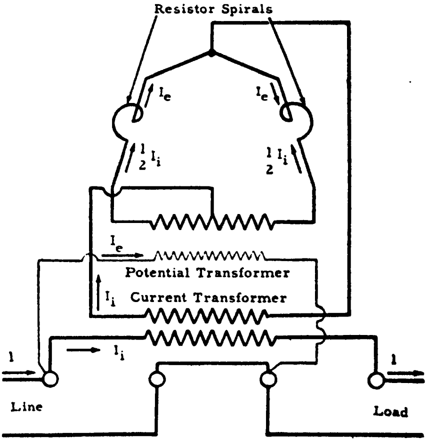


Fig. 4-17. Schematic Circuit Arrangement for Directly Heated Thermal Demand Meter

As the bimetallic strips affected by the heaters oppose each other, the movement of the shaft to which the bimetallic coils are attached, will be proportional to

$$(I_e + \tfrac{1}{2}I_i)^2 - (I_e - \tfrac{1}{2}I_i)^2 = 2I_eI_i,$$

which in turn is directly proportional to power. As the currents in the heaters add vectorially, the movement of the shaft will be in proportion to watts in the line at any power factor.

As the shaft which is attached to the bimetallic expansion coils turns on its bearings, it bears against a movable pointer, pushing it upscale to a position of maximum deflection, at which point it remains until manually reset to some lower point on the scale, which may or may not be the zero position. Since the pusher pointer follows the load variations with its characteristic time lag, it will be at some position other than zero if there is load on the circuit. Therefore, if there is load on the circuit at the time of resetting the maximum pointer, this pointer cannot be returned to zero but can only be made to coincide, in scale reading, with the position of the pusher-pointer.

Due to heat storage capacity of the meter element, the temperature of the bimetallic coils and hence the indication of the meter does not immediately respond to changes of load but follows load changes according to a heating or exponential curve. A typical curve is shown in Fig. 4-18.

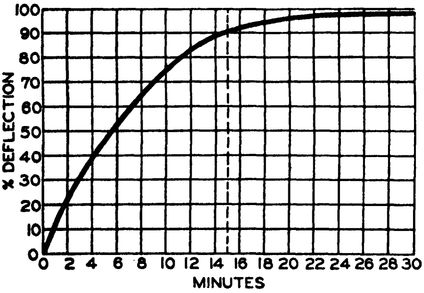


Fig. 4-18. Characteristic Response Curve of a 15-Minute Thermal Demand Meter With Constant Load

When load is applied to such a meter, having a 15 minute demand interval, 15 minutes is required for the meter to indicate 90% of the load change, and 30 minutes to indicate 99% as shown in Fig. 4-18. Meters are also produced with time characteristics such that 30 minutes is required to indicate 90% of a change in load.

The effect of external heating from the sun or some radiant source of heat is negligible since the actuating element is for all practical purposes effectively shielded against such effects. Temperature effects are further compensated for by the use of special compensating devices peculiar to each design and are fully discussed in manufacturers' literature.

It should be noted that thermal watt demand meters may, by the use of proper accessories and connections, be used for the measurement of kilovar and kilovolt-ampere demands.

Thermal ampere demand meters as well as thermal watthour demand meters are now available in a variety of forms such as separate units, in combination with watthour meters both "A" and "S" mountings, and as recording or curve-drawing instruments.

A mechanically-lagged demand register is essentially one in which the indications and response characteristics parallel the characteristics of the thermal demand meter but are obtained by mechanical means.

Referring to Fig. 4-19, *A* and *B* are small bevel crown gears which with a planetary gear *G* form a differential which through the relative speeds of its parts controls the angular position of the planetary gear *G* which carries with it an involute cam *C*. The cam *C* is mounted on a shaft which connects with the demand pointer *D*.

A solid aluminum ball rests against the edge of the cam and is positioned between a driving disk *E* and a driven drum or roller *F*. At the "zero" position of the cam, the demand pointer is at zero on the scale and the ball is held at the exact center of the driving disk *E*. The gear *A* of the differential is driven by the watthour meter with a proper reduction in speed and the gear *B* is driven by the drum *F* of the ball mechanism.

As long as there is no load on the watthour meter, and if the ball is at the zero position, as previously mentioned, the differential remains at rest and the driving disk *E* simply rotates at a constant speed due to a connection with the synchronous timing motor, but no motion is imparted to the ball and the demand pointer remains at zero.

When a load is applied to the watthour meter, its side of the differential is driven at a speed proportional to this load, the cam begins to move, and since the drum *F* is tilted at a slight angle, the ball follows the cam and moves a little away from the center of disk *E*. Immediately the ball begins to rotate about an axis which is parallel to the drum and which passes through the contact point between the ball and cam so that there is no friction at this point to prevent free rotation. Since the ball is resting on the drum *F* and rotating about a parallel axis, the drum is driven at the same surface speed as the ball and, in turn, drives the gear *B* in a direction which is arranged to be opposite to that of gear *A*. Thus the motion of the planetary gear *G* with the cam *C* is equal to the difference between *A* and *B*; therefore, if for any position the speed of *B* is equal to *A*, the cam remains in that position. Referring again to the position of the ball against the driving disk *E*, it is evident that the rotational speed of the ball and,

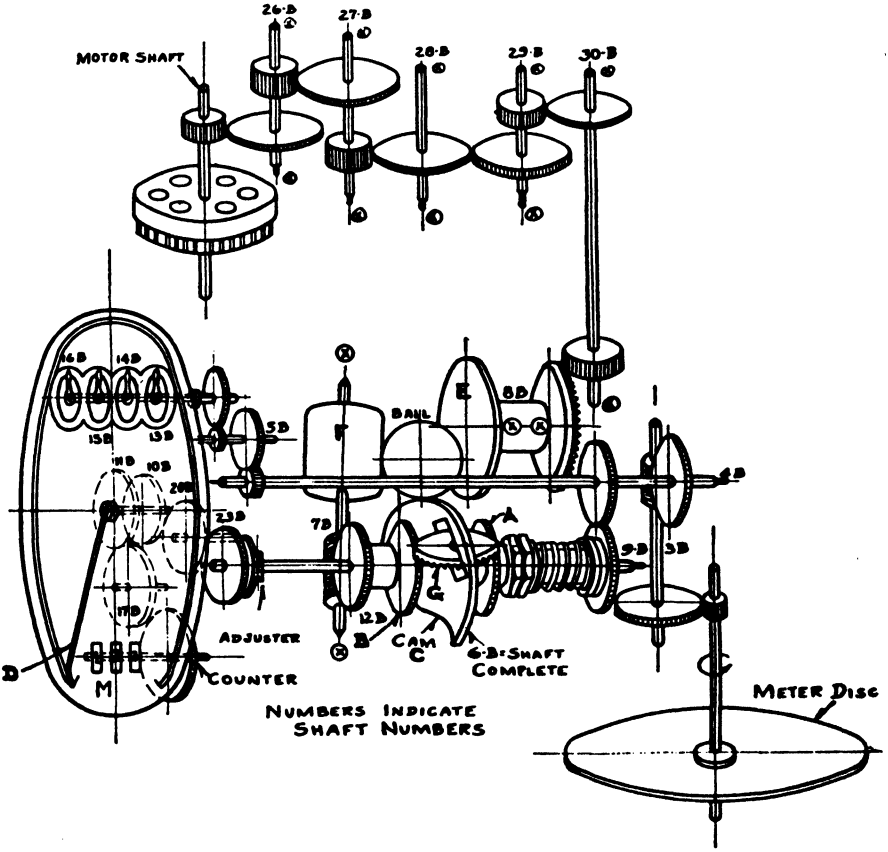


Fig. 4-19. Schematic Arrangement of Mechanically-lagged Watthour Demand Meter

consequently, of the drum *F* is proportional to the distance of the ball contact point from the center of the disk *E*, which distance is exactly proportional to the angular position of the cam since the radius or "rise" of an involute cam is exactly proportional to its angular position. Then, for any given load and corresponding rotational speed of *A*, there is a definite position of the cam which will give an equal and opposite speed of *B*; therefore, the cam simply moves until this balance point is reached and remains there until the load on the watthour meter changes to a new value.

Since the rate at which the cam with the demand pointer *D* moves is equal to the difference in speed between *A* and *B*, it is evident that this rate starts off at a relatively high value, then becomes less and less as *A* minus *B* approaches zero, and the time to reach the balance point is very long. Thus the advance of *D* over the demand scale is rapid at first but becomes less and less as the final position is approached. For the same change in load, the descending rate as the demand pointer returns to zero is exactly the same as the ascending rate. Thus if the watthour meter stops, the gear *B* simply continues to rotate and carries the cam in the reverse direction at a slower and slower speed until finally the ball is again at the center of the disk *E* and all motion ceases.

The maximum demand pointer which is advanced by the resultant rotation of the differential gear assembly remains, due to a friction device, at the highest position to which it has been carried, until manually reset to zero at the reading period. The pusher assembly, like its counterpart in the thermal demand meter, follows the variation of the metered load with the characteristic time lag of such devices.

Fig. 4-20 is a characteristic curve of this type of demand register. Its similarity with the corresponding curve of the thermal demand meter is evident.

SPECIFICATIONS FOR INDICATING THERMAL WATT DEMAND METERS

As mentioned previously in this section, the manufacture of thermal demand meters has been increased several fold within the last few years. In anticipation of this growth and in the interest of standardization the Committee on Metering and Service Methods, Association of Edison Illuminating Companies, jointly with the Meter and Service Committee, Edison Electric Institute, have written a specification, designated MS-5–1946 which appears on the following pages.

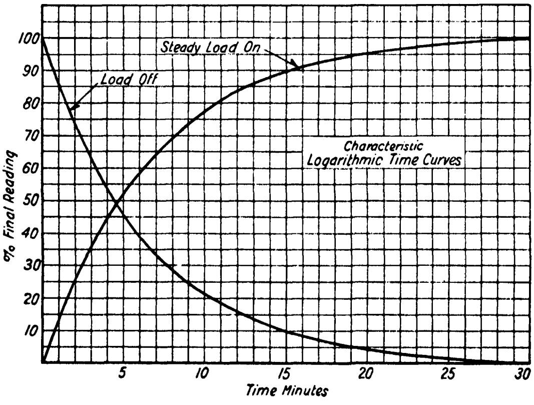


Fig. 4-20. Characteristic Load Time Curves of a Mechanically-lagged Demand Register

MS-5
1946

SPECIFICATIONS FOR
INDICATING THERMAL WATT DEMAND METERS

THIS set of specifications is one of a series covering meters, metering equipment, and services. It is issued by the Joint Committee on Industry Standards under the sponsorship of the Committee on Metering and Service Methods of the Association of Edison Illuminating Companies, and the Meter and Service Committee of the Edison Electric Institute. The specifications are approved by these sponsors groups.

This document is intended to be used as an aid in preparing specifications for purchase and use. It is issued as engineering information and in the expectation that it may be useful in promoting uniform practices. Its observance is not intended to be mandatory and no one concerned with its preparation has authority to make such a requirement. There may be other good means for attaining similar results, but acceptance is urged on the basis of simplified stock, manufacturing requirements, and economic advantages to all interested parties.

1. SCALE CLASSES

Thermal watt demand meters and the demand element of watthour thermal demand meters for operation on 60 cycles shall be provided in the following scale classes expressed as a percentage of the nominal Kw rating of the meter:

Class 1—$166\frac{2}{3}$% of Nominal Kw Rating of meter.
Class 2—$333\frac{1}{3}$% of Nominal Kw Rating of meter.
Class 3—200% of Nominal Kw Rating of meter.

NOTE: The nominal Kw ratings of the meter are derived as follows:

$$\text{Kw Rating} = \frac{E \times I \times \text{No. of Elements*}}{1{,}000}$$

where E (S.C. Meters) = 120 or Multiples Thereof
E (P.T. Meters) = 120 × P.T. Ratio
I (S.C. Meters) = Nominal Current Rating of Meter
I (C.T. Meters) = Nominal Current Rating of Meter ($2\frac{1}{2}$ or 5) × C.T. Ratio

Class 1, 2, and 3 scales shall be provided for self-contained meters, and for meters for use with current transformers having 5-ampere secondary ratings, in the nominal ampere, voltage, and element ratings as shown in Table I.

In addition to the scales shown in Table I, a 100-division universal scale marked 0-1.0, and a 100-division universal scale marked 0–100 shall be provided to which multiplying factors based on the full scale values shown in the table would apply.

* 2 Elements, 3 Phases, 4 Wire Wye Meters considered as having 3 elements.

2. DEMAND INTERVAL

Thermal watt demand meters shall have either a nominal 15- or a nominal 30-minute demand interval. The demand element of watthour thermal demand meters shall have a nominal 15-minute demand interval.*

NOTE: Demand interval to be in accordance with Article 921 of Code for Electricity Meters, Fourth Edition.

* Established by present design.

3. MULTIPLYING CONSTANTS

The demand scale when not of the direct reading type, shall be provided with a remov-

TABLE I—FULL SCALE VALUE IN KILOWATTS

Ampere Rating	Class	120 V, 1-Element	240 V, 1-Element; 120 V, 2-Element	120 V, 3-Element	240 V, 2-Element	240 V, 3-Element	480 V, 2-Element
2.5 C.T.	2	1.0	2.0	3.0	4.0	6.0	8.0
5 C.T.	1	1.0	2.0	3.0	4.0	6.0	8.0
15	2	6.0	12.0	18.0	24.0	36.0	48.0
50	3	12.0	24.0	36.0	48.0	72.0	96.0
Optional Standards							
2.5 C.T.	1	0.5	1.0	1.5	2.0	3.0	4.0
15	3	3.6	7.2	10.8	14.4	21.6	28.8

able tag on the scale plate labelled "MULTIPLY DEMAND BY ——."

Kilowatt hour multiplying constants shall conform to E.E.I. Specification MS-1 "Standard Dial Constants for Alternating Current Watthour Meters."

4. NAMEPLATES

The thermal watt demand meter nameplate shall contain the following minimum information:

Type————————————
Serial No.——————————
Amperes——————————
Volts———————————
Phase———————————
Wire————————————
Element*————————————
Cycle———————————
Demand Interval†——————
Full Scale Value—————————

* May be omitted on single-phase meter.

† The words "demand interval" shall not appear on the nameplate, "t 15" or "t 30" being the only designation to indicate demand interval.

The watthour thermal demand meter nameplate shall contain the following minimum information applying specifically to the demand element:

Demand Interval‡——————
Full Scale Value—————————

‡ The words "demand interval" shall not appear on the nameplate, "t 15" being the only designation to indicate demand interval.

5. TYPE OF INDICATING POINTER

The indicating pointer shall be so designed with relation to the scale that parallax errors are minimized. The thickness of that part of the pointer over the scale divisions should not exceed twenty thousandths (0.020) inch.

6., MARKING OF DEMAND FACE PLATES

The word "DEMAND" should be placed preferably directly under the demand scale at the center of the scale plate.

7. LENGTH OF SCALE

The scale shall be at least four (4.0) inches in length.

8. SCALE DESIGN

The number of scale divisions shall be as shown in Table II.

Lines of different length and width shall be used for the main "M," intermediate "I," and sub "S" division markings. In addition the subdivision markings shall be bounded by arc lines.

TABLE II—SCALE DIVISIONS

Kw	Kw	Number of Divisions	
Full Scale	per Division	Total	M—I—S
0.5	0.01	50	5—2—5
1.0*	0.01	100	10—2—5
1.5	0.02	75	15—0—5
2.0	0.02	100	20—0—5
3.0	0.05	60	6—5—2
3.6	0.05	72	7—5—2 + 2
4.0	0.05	80	8—5—2
6.0	0.1	60	6—2—5
7.2	0.1	72	7—2—5 + 2
8.0	0.1	80	8—2—5
10.8	0.2	54	10—0—5 + 4
12.0	0.2	60	12—0—5
14.4	0.2	72	14—0—5 + 2
18.0	0.2	90	18—0—5
21.6†	0.5	43	21—0—2 + 1
24.0	0.5	48	24—0—2
28.8†	0.5	58	29—0—2
36.0	0.5	72	7—5—2 + 2
48.0	0.5	96	9—5—2 + 6
72.0	1.0	72	7—2—5 + 2
96.0	1.0	96	9—2—5 + 6
100.0‡	1.0	100	10—2—5

* Universal and direct reading scale.

† Scale length does not give exact value.

‡ Universal scale only.

SECTION 5

INSTRUMENT TRANSFORMERS

There are two general classes of instrument transformers, potential transformers and current transformers. These transformers are used in connection with meters and instruments for two reasons: first, as a protection to life from contact with high voltage circuits, and second, to reduce the voltage and current applied to the meters or instruments to values that will permit of practical design. In practice, it is generally desirable or necessary to use current transformers for currents in excess of 100 amperes, and to use current and potential transformers for voltages in excess of 240 volts.

An instrument transformer delivers to the meter to which it is connected a voltage or current which is always proportional to the primary voltage or current, and it insulates the meter from line voltage. Generally the secondary of a potential transformer is designed for 120 volts for those rated 25 kv and below, and for 115 volts for those rated 34.5 kv and above. The secondary of a current transformer generally is designed for 5 amperes at rated primary current.

There are three essential parts to an instrument transformer: a primary electrical circuit; a secondary electrical circuit; and a magnetic circuit or core, with which these are interlinked. The primary winding is connected to the supply circuit, and the secondary winding to the measuring apparatus. See Fig. 5-1.

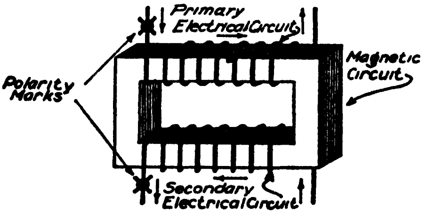


Fig. 5-1. Essential Parts of an Instrument Transformer

POTENTIAL TRANSFORMERS

Uses

Potential transformers are used to step down service voltage for meters, instruments, relays, and auxiliary metering and station apparatus. One transformer can be used for a number of instruments if the total burden of the instruments does not exceed that for which the transformer is designed and compensated.

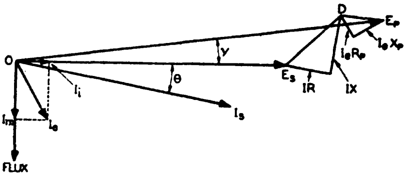


Fig. 5-2. Vector Diagram of a Potential Transformer

Principle of Operation

The potential transformer is designed for close regulation, so that the secondary voltage under any conditions will be as nearly as possible a fixed percentage of the primary voltage.

In general, the induced secondary voltage is nearly equal to the primary voltage divided by the ratio of turns, primary to secondary, and opposite in phase to the primary voltage. On account of the losses in the transformer and the magnetic leakage between coils, the true ratio is not exactly equal to the turn or marked ratio, and a phase difference between the primary voltage and the reversed secondary voltage is produced. This is shown by the vector diagram, Fig. 5-2, where a 1:1 ratio is assumed. The conclusions drawn hold good in other ratios. The deviation of the true ratio from the marked ratio is generally called the ratio error, and the phase difference is called the phase angle of the transformer. The amount of ratio error and the value of the phase angle will depend upon the load connected to the secondary of the transformer. This load is the secondary burden.

OE_s	represents the reversed secondary voltage delivered to the meters.
OI_s	represents the reversed secondary current delivered to the meters.
θ	represents the angle of lag of the secondary current behind the secondary voltage and is determined by the relation of resistance to reactance in the instruments.
OI_i	represents the current in the primary winding to supply the iron loss of the transformer (hysteresis and eddy currents).
OI_m	the current to magnetize the core.
OI_e	the total exciting current. This is the vector sum of OI_i and OI_m and it flows in the primary winding only.
IR	is the voltage drop due to the burden current I_s and the resistance of both primary and secondary windings. It is parallel to OI_s.
IX	is the reactance drop due to the burden current and is perpendicular to OI_s.
OD	would therefore be the primary voltage if the iron required no exciting current. But the exciting current, flowing in the primary coil only, causes a drop in voltage
I_eR_p	due to the resistance of the primary coil and parallel to OI_e and
I_eX_p	due to the reactance of the primary coil and perpendicular to OI_e.
OE_p	therefore, represents the total primary voltage necessary to deliver the burden current OI_s at the secondary voltage OE_s. It differs from OE_s both in magnitude and in phase position.
γ	represents the phase angle between primary and secondary voltage reversed.

There are two classes of errors in measurement produced by potential transformers. One is due to deviation of the actual ratio from the marked ratio, or ratio error, and the other is due to the phase displacement of the secondary voltage reversed with respect to the primary voltage, or phase angle.

The amount of ratio error and the phase angle at a particular value of primary voltage and secondary burden determines the accuracy of the potential transformer at that condition of primary voltage and secondary burden.

That part of the ratio error and phase angle due to the secondary burden varies directly with the burden and can be minimized by making the resistance and reactance of the windings very low.

The ratio error is materially reduced by adjusting the turn ratio to make up for the voltage drop in the secondary due to burden. Transformers are usually so compensated for some particular secondary burden. Compensation for error due to phase angle is not usually provided, but modern designs are such that ratio errors and phase angles are relatively small within the rating of the transformer.

Permanence of Accuracy

The accuracy of a potential transformer does not change appreciably with age. It may change, however, due to a mechanical defect or electrical failure in the transformer.

Effect of Variation in Primary Voltage

Potential transformers are compensated for iron losses at rated voltage. When used at other than rated voltage an error is introduced, but it will not be appreciable when the applied voltage is within ±10% of rated voltage.

Effect of Frequency Variation and Wave Form

Ordinary operating variations of frequency and wave form have a negligible effect on the accuracy of potential transformers.

CURRENT TRANSFORMERS

Uses

The current transformer provides a means of producing a current proportional to the primary current and of insulating the meter from the primary circuit. It is an application of the transformer principle to obtain a constant ratio of primary to secondary current over a wide range of current.

Current transformers may be used with meters, instruments, relays and auxiliary metering apparatus. One current transformer may be used to operate several instruments and meters provided the combined burden does not exceed that for which the transformer is designed and compensated.

Principle of Operation

As previously outlined the potential transformer is connected across the line, or from line to neutral, and the magnetic flux in the core depends upon the primary voltage. For a given voltage the flux is fixed, while the current in the winding varies with the secondary burden. On the other hand, the current transformer is connected in series with the line. For a fixed number of instruments in the secondary a change in the line current requires a corresponding change in the secondary voltage to keep the secondary current proportional to the primary current. The magnetic flux in the iron, which supplies this voltage, thus follows the change in the primary or line current.

In any transformer, the primary ampere-turns may be considered as made up of two portions, one small portion which supplies the magnetizing and core loss current, and the larger portion which supplies the "working current." The "working current" ampere-turns are always exactly equal to the secondary ampere-turns. For the current transformer, these elements may be shown graphically as in Fig. 5-3.

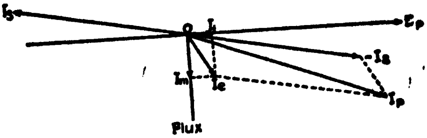


Fig. 5-3. Ampere-turn Vectors

The total primary ampere-turns, OI_p, are the vector sum of the exciting current ampere-turns, OI_e, and the primary "working current" ampere-turns, OI_s. The primary "working current" ampere-turns are exactly equal to the secondary ampere-turns, OI_s. The exciting current is made up of two parts, OI_m, the ampere-turns required to magnetize the core, and OI_t, the ampere-turns required to supply the hysteresis and eddy current losses in the core. The vectors show the phase relation of the various currents.

If the exciting current in Fig. 5-3 could be reduced to zero, the secondary ampere-turns would equal the primary ampere-turns and would be exactly in phase opposition. The transformer would then produce a current in the meter which would, under all conditions, be proportional to the line current. Fig. 5-3 indicates that there is a deviation of the true ratio from the turn ratio or a ratio error, since the vector OI_s is not quite equal in length to the vector OI_p; and also a phase displacement or phase angle since the vector OI_s is not exactly in phase opposition to the vector OI_p. The losses in the core cause both of these inherent errors, and for that reason the cores of current transformers are designed so that the density of the magnetic flux and the resulting losses are low. The vector diagram is exaggerated because the actual losses are extremely small.

If the exciting current decreased exactly in proportion to a decrease in the primary current, all vectors in Fig. 5-3 would decrease in the same ratio, and the ratio error would be constant for all primary currents. However, Fig. 5-4 indicates that at a flux density corresponding to one-half

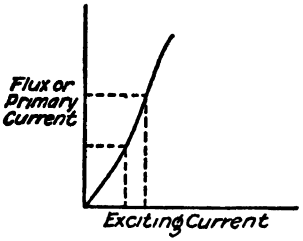


Fig. 5-4. Typical Curve of Exciting Current

normal primary current, the exciting current is more than one-half of its value at full primary current, and the exciting current therefore does not decrease in proportion to the decrease in the primary current.

Thus the ratio error and phase angle vary with the primary current as well as with secondary burden. Therefore, by properly proportioning the windings, it is possible to compensate for ratio error at one value of primary current and one secondary burden only. The phase angle can also be compensated for or reduced for one value of primary current and secondary burden by special windings or cores. Modern designs are such that a balance over the transformer rating is achieved; and for all values of primary current or secondary burden within the rating, the ratio errors and phase angle variations are relatively small.

There are, then, two classes of errors in measurement produced by current transformers which are similar to those produced by potential transformers. One is due to deviation of the actual ratio from the marked ratio, or ratio error, and the other is due to the phase displacement of the secondary current reversed with respect to the primary current, or phase angle.

The amount of ratio error and the phase angle at a particular value of primary current and secondary burden determines the accuracy of the current transformer at that condition of primary current and secondary burden.

Permanence of Accuracy

The accuracy of a current transformer does not change appreciably with age. It may, however, change due to a mechanical defect or electrical failure in the transformer.

Magnetization of Core

The core may become magnetized, either by accidentally passing direct current through the transformer, by opening the secondary circuit with a load on the primary, or by a heavy overload on the primary. If magnetized, iron loss and magnetizing current will be abnormally high and the ratio and phase-angle errors will be slightly greater than normal. A transformer can be demagnetized and restored to normal by passing about 150 per cent of normal current through the primary, with a resistance of 20 to 30 ohms connected in the secondary, and gradually reducing the resistance to zero. Care should be taken not to open-circuit the secondary during this operation.

Effect of Frequency Variation

Frequency variation has little effect on the accuracy of a current transformer having high internal impedance. A properly designed current transformer may generally be operated on the usual range of commercial frequencies from 25 to 133 cycles.

Effect of Wave Form

The shape of the primary current wave affects, to some extent, the maximum induction and therefore the iron losses, and also affects the shape of the secondary current wave, which may introduce errors. But these are, in general, negligible.

INHERENT DESIGN COMPENSATION FOR RATIO ERROR AND PHASE ANGLE

Ratio errors and phase angles in instrument transformers are due to the exciting current which is required to maintain the magnetic flux and to supply core losses. Ratio errors are, in general, compensated by changing the number of secondary turns of the transformer. Only ratio error compensation is generally applied to potential transformers, because phase angle compensation is not generally practical. Proper design keeps phase angle small. Phase angles in current transformers, however, are generally compensated in some practical manner.

The ratio compensation has no effect on the phase angle of the current transformer. In order to minimize the effect of core losses and magnetization currents, the flux density must be kept low or the permeability of the magnetic material must be high, or the two factors combined to produce the desired effect.

There are two practical methods in general use for reducing ratio errors and phase angles:

1. The use of core material of nickel-iron alloys with relatively high resistivity and high permeability.
2. The use of compensating turns of the secondary winding through the magnetic core, or other types of compensating windings.

Nickel-Iron Alloys

Nickel-iron alloys are used as core material to improve performance characteristics of instrument transformers. Its increased resistivity reduces eddy current losses. Its hysteresis loss is extremely low, and its permeability is many times that of Silicon steel. The result is that a much lighter weight core is possible, and materially reduced ratio errors and phase angles are obtained.

Compensating Windings

One method of compensation is by the use of compensating turns in the core of the transformer. In one such method, ratio compensation is accomplished by having holes in each of the two legs of the core, dividing the core into two paths of unequal cross section, and a few turns wound through each hole in series with the transformer secondary as shown in Fig. 5-5a. At lower values of the primary current, the flux will divide a certain proportion between paths A and B and A′ and B′.

As the primary current increases, a greater portion of the flux will pass through paths B and B′ because of a change in the relative permeability of these parts, thus causing corrective turns to have a diminishing effect as current increases. The phase angle correction consists of a short-circuited turn of wire around the sections A or A′ or both. The action of this coil is similar to that of the lag plate of a watthour meter.

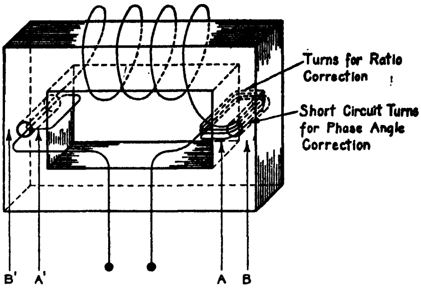

Turns for Ratio Correction
Short Circuit Turns for Phase Angle Correction
B'
A'
A
B

Fig. 5-5a. Compensating Winding for Correcting Instrument Transformers for Inherent Errors

A second method of winding compensation is accomplished by dividing the core into two parallel paths and suitably proportioning the secondary winding between the two paths. Fig. 5-5b shows this general arrangement which is called a "biased core" current transformer. In this arrangement, the biasing winding introduces a compensating current that is proportional to and a constant percentage of the secondary current and is made by design of such value as to reduce the overall ratio error and phase angle of the transformer.

Other methods of compensation have been developed and used but the two discussed here are the more usual ones.

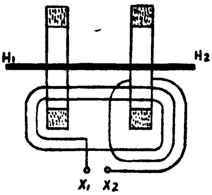


Fig. 5-5b. Biased Core Current Transformer

EFFECT OF INSTRUMENT TRANSFORMERS ON THE ACCURACY OF MEASUREMENT

The values of ratio error and phase angle of an instrument transformer are called *instrument transformer errors*. They cause errors in measurement when instrument transformers are used in connection with meters and measuring instruments.

These characteristics are, therefore, generally considered from the standpoint of their effect on the accuracy of instruments, meters and devices with which they are used. Usually this effect is put in the form of multipliers by which the measured quantities indicated or recorded must be multiplied to obtain the corrected or true values. The multipliers are generally called correction factors.

Advantage is taken of this fact in the design of modern instrument transformers and this, together with the very small ratio errors and phase angles now possible with modern materials and designs, results in final correction factors so small that normally they need not be considered in a modern commercial meter installation. They usually need only be considered where the most precise results are desirable.

Ratio Correction Factor (*RCF*)

As previously discussed, the ratio error of an instrument transformer is a measure of the deviation of the actual or true ratio under a given condition of use from its marked ratio or that appearing on its name plate.

If the true ratio is greater than the marked ratio, then the true secondary quantity is less than would be indicated by the marked ratio, and a meter connected to the secondary would read low by a consideration of marked ratio only. Similarly, if the true ratio is lower than the marked ratio the meter reading is proportionately high.

The factor by which the marked ratio of a current or potential transformer must be multiplied to obtain the true ratio is called the ratio correction factor (*RCF*). Ratio correction factor is also the per cent registration to which a watthour meter must be adjusted to correct for ratio error. The *ratio error* equals ($RCF - 1$).

The term *per cent ratio error* is sometimes used and equals 100% ($RCF - 1$).

The term per cent ratio (or per cent marked ratio) is also sometimes used and is equal to 100% (*RCF*).

If the true ratio is higher than the marked ratio, the *RCF* is greater than 1 and if lower, the *RCF* is less than 1.

As an example, if the *RCF* is, say, 1.005, the ratio error is +0.005, the per cent ratio error is +0.5% and the per cent ratio is 100.5%. The transformer would cause a meter to register low by $(1/1.005 - 1) \times 100$, or 0.5% for all practical purposes, and the meter registration must be multiplied by the *RCF* or 1.005 to obtain the corrected or true metered value. To correct for the error the meter would be adjusted to 1.005 (100.5%).

If the *RCF* is, say 0.995, the ratio error is −0.005, the per cent ratio error is −0.5% and the per cent ratio is 99.5%. The transformer would cause a meter to register high by $(1/0.995 - 1) \times 100$, or 0.5% for all practical purposes, and the meter registration must be multiplied by the *RCF* or 0.995 to obtain the corrected or true metered value. To correct for the error the meter would be adjusted to 0.995 (99.5%).

Where both a current and potential transformer are used, as in the measurement of watts, the combined ratio correction factor is:

$$RCF_K = RCF_E \times RCF_I$$

where RCF_K is the combined ratio correction factor,

RCF_E is the potential transformer ratio correction factor, and

RCF_I is the current transformer ratio correction factor.

Phase Angle Correction Factor (*PACF*)

The phase angle of a potential transformer is defined as the angle between the primary voltage vector and the secondary voltage vector reversed.

It is preferably designated by the symbol γ.

The phase angle of a current transformer is defined as the angle between the primary current vector and the secondary current vector reversed.

It is preferably designated by the symbol β.

These angles are conveniently considered as positive when the reversed secondary vector leads the primary vector, and they are usually measured in minutes. While present conventions of the sign of the phase angle are well established, in the case of potential transformers different authorities and manufacturers have used the opposite signs at various times. In using older data for potential transformers, it is important to check, and if necessary reverse the sign of the phase angle in making calculations of accuracy settings. The factor by which the reading of a wattmeter or watthour meter, operated from the secondary of a current or potential transformer or both, must be multiplied to correct for the effect of phase displacement of current and voltage due to the measuring apparatus is called the phase angle correction factor (*PACF*). Phase angle correction factor is also the per cent registration to which the meter must be adjusted to correct for phase angle at the given load and power factor.

Tables 5-A and 5-B show phase angle correction factors at various power factors.

The *PACF* for a given condtion of the metered load is dependent both upon the phase angle introduced by the instrument transformers and the power factor angle of the metered load. It is for this reason that the phase angle must be kept small in the design of a transformer.

Since by convention a sign has been given the phase angle, it is also convenient to associate a sign with the power factor angle for the purpose of adding or subtracting the angles in determining their effect.

In the following derivations the power factor angle is considered as positive when the current vector lags the voltage vector, and negative when the current vector leads the voltage vector. This means that for a lagging power factor angle of less than 180°, the power factor angle as measured from the current vector to the voltage vector would be positive.

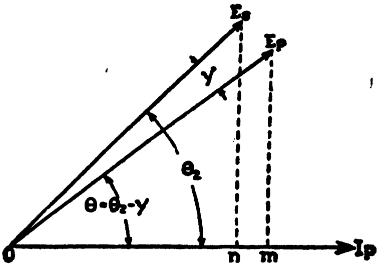


Fig. 5-6. Effect of Phase Displacement of a Potential Transformer

Fig. 5-6 shows a vector diagram of the current and potential where it is assumed a potential transformer only is used to measure watts or watthours. γ is the phase angle of the potential transformer and is positive since the secondary voltage vector reversed leads the primary voltage vector. θ is the power factor angle of the metered load and is positive, and θ_2 is the angle between the secondary voltage and the current at the meter. It is called the apparent power factor angle and is also positive. The difference between line power factor and apparent power factor is usually so small that for ordinary values of phase angle the computed value of the *PACF* will be, for all practical purposes, the same when computations are made on the assumption that line power factor and apparent power factor are equal.

Fig. 5-7 shows a vector diagram of the currents and potential where a current transformer only is used to measure watts or watthours.

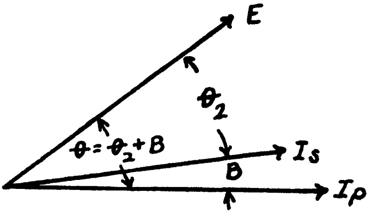


Fig. 5-7. Effect of Phase Displacement of a Current Transformer

TABLE 5-A

CORRECTION FACTORS $\left(\frac{\cos\theta}{\cos\theta_2}\right)^*$ FOR PHASE ANGLE

For Lagging Current when $(\beta - \gamma)$ is Positive
For Leading Current when $(\beta - \gamma)$ is Negative

Phase Angle $(\beta - \gamma)$	APPARENT POWER FACTOR $(\cos\theta_2)$													
	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95	0.99	1.00
5′	0.9855	0.9904	0.9929	0.9944	0.9954	0.9967	0.9975	0.9981	0.9985	0.9989	0.9993	0.9995	0.9998	1.0000
10′	0.9711	0.9808	0.9857	0.9887	0.9907	0.9933	0.9950	0.9961	0.9970	0.9978	0.9986	0.9990	0.9996	1.0000
15′	0.9566	0.9712	0.9786	0.9831	0.9861	0.9900	0.9924	0.9942	0.9955	0.9967	0.9979	0.9986	0.9994	1.0000
20′	0.9421	0.9616	0.9715	0.9775	0.9815	0.9867	0.9899	0.9922	0.9940	0.9956	0.9972	0.9981	0.9992	1.0000
25′	0.9276	0.9520	0.9643	0.9718	0.9768	0.9833	0.9874	0.9903	0.9926	0.9945	0.9965	0.9976	0.9989	1.0000
30′	0.9131	0.9424	0.9572	0.9662	0.9722	0.9800	0.9848	0.9883	0.9911	0.9934	0.9957	0.9971	0.9987	1.0000
40′	0.8842	0.9232	0.9429	0.9549	0.9629	0.9733	0.9798	0.9844	0.9881	0.9912	0.9943	0.9961	0.9983	0.9999
50′	0.8552	0.9040	0.9286	0.9436	0.9536	0.9666	0.9747	0.9805	0.9851	0.9890	0.9929	0.9951	0.9978	0.9999
1° 0′	0.8262	0.8848	0.9143	0.9323	0.9444	0.9599	0.9696	0.9766	0.9820	0.9868	0.9914	0.9941	0.9974	0.9998
10′	0.7972	0.8656	0.9000	0.9209	0.9350	0.9531	0.9645	0.9726	0.9790	0.9845	0.9899	0.9931	0.9969	0.9998
20′	0.7682	0.8464	0.8857	0.9096	0.9257	0.9464	0.9594	0.9687	0.9760	0.9823	0.9885	0.9921	0.9964	0.9997
30′	0.7392	0.8271	0.8714	0.8983	0.9164	0.9397	0.9543	0.9648	0.9730	0.9800	0.9870	0.9911	0.9959	0.9997
40′	0.7102	0.8079	0.8571	0.8869	0.9071	0.9329	0.9492	0.9608	0.9699	0.9778	0.9855	0.9900	0.9954	0.9996
50′	0.6812	0.7886	0.8428	0.8756	0.8978	0.9262	0.9441	0.9568	0.9668	0.9755	0.9840	0.9890	0.9949	0.9995
2° 0′	0.6521	0.7694	0.8284	0.8642	0.8884	0.9194	0.9389	0.9529	0.9638	0.9732	0.9825	0.9879	0.9944	0.9994
10′	0.6231	0.7501	0.8141	0.8529	0.8791	0.9127	0.9338	0.9489	0.9607	0.9709	0.9810	0.9869	0.9939	0.9993
20′	0.5941	0.7308	0.7997	0.8415	0.8697	0.9059	0.9287	0.9449	0.9576	0.9686	0.9795	0.9858	0.9934	0.9992
30′	0.5650	0.7115	0.7854	0.8301	0.8603	0.8991	0.9235	0.9409	0.9545	0.9663	0.9779	0.9847	0.9928	0.9990
40′	0.5360	0.6923	0.7710	0.8187	0.8510	0.8923	0.9183	0.9369	0.9515	0.9640	0.9764	0.9836	0.9923	0.9989
50′	0.5069	0.6730	0.7566	0.8073	0.8416	0.8855	0.9132	0.9329	0.9483	0.9617	0.9748	0.9825	0.9917	0.9988
3° 0′	0.4779	0.6537	0.7422	0.7959	0.8322	0.8787	0.9080	0.9288	0.9452	0.9594	0.9733	0.9814	0.9912	0.9986
10′	0.4488	0.6344	0.7279	0.7845	0.8228	0.8719	0.9028	0.9248	0.9421	0.9570	0.9717	0.9803	0.9906	0.9985
20′	0.4198	0.6151	0.7135	0.7731	0.8134	0.8651	0.8976	0.9208	0.9390	0.9547	0.9701	0.9792	0.9900	0.9983
30′	0.3907	0.5957	0.6991	0.7617	0.8040	0.8583	0.8924	0.9167	0.9359	0.9523	0.9686	0.9781	0.9894	0.9981
40′	0.3616	0.5764	0.6847	0.7503	0.7946	0.8514	0.8872	0.9127	0.9327	0.9500	0.9670	0.9769	0.9888	0.9980
50′	0.3326	0.5571	0.6702	0.7388	0.7852	0.8446	0.8820	0.9086	0.9296	0.9476	0.9654	0.9758	0.9882	0.9978
4° 0′	0.3035	0.5378	0.6558	0.7274	0.7758	0.8377	0.8767	0.9046	0.9264	0.9452	0.9638	0.9746	0.9876	0.9976
10′	0.2744	0.5185	0.6414	0.7160	0.7663	0.8309	0.8715	0.9005	0.9232	0.9429	0.9622	0.9735	0.9870	0.9974
20′	0.2453	0.4991	0.6270	0.7045	0.7569	0.8240	0.8663	0.8964	0.9201	0.9405	0.9605	0.9723	0.9864	0.9971
30′	0.2163	0.4798	0.6125	0.6930	0.7474	0.8171	0.8610	0.8923	0.9169	0.9381	0.9589	0.9711	0.9857	0.9969
40′	0.1872	0.4604	0.5981	0.6816	0.7380	0.8103	0.8558	0.8882	0.9137	0.9357	0.9573	0.9699	0.9851	0.9967
50′	0.1581	0.4411	0.5837	0.6701	0.7285	0.8034	0.8505	0.8841	0.9105	0.9333	0.9556	0.9687	0.9844	0.9964
5° 0′	0.1290	0.4217	0.5692	0.6586	0.7191	0.7965	0.8452	0.8800	0.9073	0.9308	0.9540	0.9675	0.9838	0.9962
10′	0.0999	0.4024	0.5548	0.6472	0.7096	0.7896	0.8400	0.8759	0.9041	0.9284	0.9523	0.9663	0.9831	0.9959
20′	0.0708	0.3830	0.5403	0.6357	0.7001	0.7827	0.8347	0.8717	0.9008	0.9260	0.9507	0.9651	0.9824	0.9957

* $\frac{\cos\theta}{\cos\theta_2}$ may be also written $\frac{\cos(\theta_2 + \beta - \gamma)}{\cos\theta_2}$

Interpolation for correction factors corresponding to values of $(\beta - \gamma)$ lying between those given in the table, may be made without error. Interpolation for correction factors corresponding to values of $\cos\theta_2$ lying between those given in the table may be made without exceeding an error of 0.0010 in the sections of the table lying between the heavy black lines; outside of these sections, and in all cases where the adjacent values of $\cos\theta_2$ are separated by the heavy black lines, the maximum error in interpolation will exceed 0.0010.

TABLE 5-B

CORRECTION FACTORS $\left(\frac{\cos\theta}{\cos\theta_2}\right)^*$ FOR PHASE ANGLE

For Lagging Current when ($\beta - \gamma$) is Negative
For Leading Current when ($\beta - \gamma$) is Positive

Phase Angle ($\beta - \gamma$)	APPARENT POWER FACTOR ($\cos\theta_2$)													
	0.10	0.15	0.20	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95	0.99	1.00
5′	1.0145	1.0096	1.0071	1.0056	1.0046	1.0033	1.0025	1.0019	1.0015	1.0011	1.0007	1.0005	1.0002	1.0000
10′	1.0289	1.0192	1.0142	1.0113	1.0092	1.0067	1.0050	1.0039	1.0030	1.0022	1.0014	1.0010	1.0004	1.0000
15′	1.0434	1.0288	1.0214	1.0169	1.0139	1.0100	1.0075	1.0058	1.0044	1.0033	1.0021	1.0014	1.0006	1.0000
20′	1.0579	1.0383	1.0285	1.0225	1.0185	1.0133	1.0101	1.0077	1.0059	1.0043	1.0028	1.0019	1.0008	1.0000
25′	1.0723	1.0479	1.0356	1.0281	1.0231	1.0166	1.0126	1.0097	1.0074	1.0054	1.0035	1.0024	1.0010	1.0000
30′	1.0868	1.0575	1.0427	1.0338	2.0277	1.0200	1.0151	1.0116	1.0089	1.0065	1.0042	1.0028	1.0012	1.0000
40′	1.1157	1.0766	1.0569	1.0450	1.0369	1.0266	1.0201	1.0154	1.0118	1.0087	1.0056	1.0038	1.0016	0.9999
50′	1.1446	1.0958	1.0711	1.0562	1.0461	1.0332	1.0251	1.0193	1.0147	1.0108	1.0069	1.0047	1.0020	0.9999
1° 0′	1.1735	1.1149	1.0853	1.0674	1.0553	1.0398	1.0301	1.0231	1.0177	1.0129	1.0083	1.0056	1.0023	0.9998
10′	1.2024	1.1340	1.0995	1.0787	1.0645	1.0464	1.0351	1.0269	1.0206	1.0151	1.0097	1.0065	1.0027	0.9998
20′	1.2313	1.1531	1.1137	1.0898	1.0737	1.0530	1.0400	1.0308	1.0235	1.0172	1.0110	1.0074	1.0030	0.9997
30′	1.2601	1.1722	1.1279	1.1010	1.0829	1.0596	1.0450	1.0346	1.0264	1.0193	1.0123	1.0083	1.0034	0.9997
40′	1.2890	1.1913	1.1421	1.1122	1.0921	1.0662	1.0500	1.0384	1.0292	1.0214	1.0137	1.0091	1.0037	0.9996
50′	1.3178	1.2104	1.1562	1.1234	1.1012	1.0728	1.0549	1.0421	1.0321	1.0235	1.0150	1.0100	1.0040	0.9995
2° 0′	1.3466	1.2294	1.1704	1.1346	1.1104	1.0794	1.0598	1.0459	1.0350	1.0256	1.0163	1.0109	1.0044	0.9994
10′	1.3755	1.2485	1.1845	1.1457	1.1195	1.0859	1.0648	1.0497	1.0379	1.0276	1.0176	1.0117	1.0047	0.9993
20′	1.4043	1.2675	1.1986	1.1569	1.1286	1.0925	1.0697	1.0535	1.0407	1.0297	1.0189	1.0126	1.0050	0.9992
30′	1.4331	1.2866	1.2127	1.1680	1.1377	1.0990	1.0746	1.0572	1.0435	1.0318	1.0202	1.0134	1.0053	0.9990
40′	1.4618	1.3056	1.2268	1.1791	1.1469	1.1055	1.0795	1.0610	1.0464	1.0338	1.0215	1.0142	1.0055	0.9989
50′	1.4906	1.3246	1.2409	1.1902	1.1560	1.1120	1.0844	1.0647	1.0492	1.0359	1.0227	1.0150	1.0058	0.9988
3° 0′	1.5194	1.3436	1.2550	1.2013	1.1650	1.1185	1.0893	1.0684	1.0520	1.0379	1.0240	1.0158	1.0061	0.9986
10′	1.5481	1.3626	1.2691	1.2124	1.1741	1.1250	1.0942	1.0721	1.0548	1.0399	1.0252	1.0166	1.0063	0.9985
20′	1.5768	1.3816	1.2832	1.2235	1.1832	1.1315	1.0990	1.0758	1.0576	1.0419	1.0265	1.0174	1.0066	0.9983
30′	1.6056	1.4005	1.2972	1.2346	1.1923	1.1380	1.1039	1.0795	1.0604	1.0439	1.0277	1.0182	1.0068	0.9981
40′	1.6343	1.4195	1.3113	1.2456	1.2013	1.1445	1.1087	1.0832	1.0632	1.0459	1.0289	1.0190	1.0071	0.9980
50′	1.6630	1.4384	1.3253	1.2567	1.2103	1.1509	1.1136	1.0869	1.0660	1.0479	1.0301	1.0197	1.0073	0.9978
4° 0′	1.6916	1.4573	1.3393	1.2677	1.2194	1.1574	1.1184	1.0906	1.0687	1.0499	1.0313	1.0205	1.0075	0.9976
10′	1.7203	1.4763	1.3533	1.2788	1.2284	1.1638	1.1232	1.0942	1.0715	1.0519	1.0325	1.0212	1.0077	0.9974
20′	1.7489	1.4952	1.3673	1.2898	1.2374	1.1703	1.1280	1.0979	1.0742	1.0538	1.0337	1.0220	1.0079	0.9971
30′	1.7776	1.5141	1.3813	1.3008	1.2464	1.1767	1.1328	1.1015	1.0770	1.0558	1.0349	1.0227	1.0081	0.9969
40′	1.8062	1.5329	1.3953	1.3118	1.2554	1.1831	1.1376	1.1052	1.0797	1.0577	1.0361	1.0234	1.0083	0.9967
50′	1.8348	1.5518	1.4092	1.3228	1.2644	1.1895	1.1424	1.1088	1.0824	1.0596	1.0373	1.0241	1.0085	0.9964
5° 0′	1.8634	1.5707	1.4232	1.3337	1.2733	1.1959	1.1472	1.1124	1.0851	1.0616	1.0384	1.0248	1.0086	0.9962
10′	1.8920	1.5895	1.4371	1.3447	1.2823	1.2023	1.1519	1.1160	1.0878	1.0635	1.0396	1.0255	1.0088	0.9959
20′	1.9205	1.6083	1.4510	1.3557	1.2912	1.2086	1.1567	1.1196	1.0905	1.0654	1.0407	1.0262	1.0089	0.9957

* $\frac{\cos\theta}{\cos\theta_2}$ may be also written $\frac{\cos(\theta_2 + \beta - \gamma)}{\cos\theta_2}$

Interpolation for correction factors corresponding to values of ($\beta - \gamma$) lying between those given in the table, may be made without error. Interpolation for correction factors corresponding to values of $\cos\theta_2$ lying between those given in the table may be made without exceeding an error of 0.0010 in the sections of the table lying between the heavy black lines; outside of these sections, and in all cases where the adjacent values of $\cos\theta_2$ are separated by the heavy black lines, the maximum error in interpolation will exceed 0.0010.

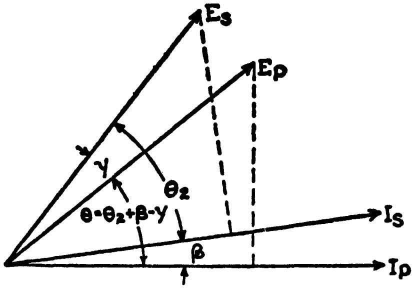


Fig. 5-8. Effect of Phase Displacement in Current and Potential Transformers

Fig. 5-8 shows a vector diagram of the currents and potentials where both a current and a potential transformer are used to measure watts or watthours.

In the case of the potential transformer, $(\theta_2 - \gamma)$ is the true power factor angle. In the case of the current transformer, $(\theta_2 + \beta)$ is the true power factor angle. For both, $(\theta_2 + \beta - \gamma)$ is the true power factor angle. In each case the angle θ_2 is the apparent power factor angle at the meter.

Therefore, the factor *PACF* for both the current and potential transformer equals the ratio of the true power factor to the apparent power factor.

$$PACF_K = \frac{\cos(\theta_2 + \beta - \gamma)}{\cos\theta_2}$$

Transformer Correction Factor (*TCF*)

The correction factor for the combined effect of ratio error and phase angle of an instrument transformer is called the transformer correction factor (*TCF*). It is the factor by which the reading of a wattmeter or watthour meter must be multiplied to correct for the effect of ratio error and phase angle. It is also the per cent registration to which a meter would be adjusted to correct for ratio and phase angle of a current or potential transformer.

$$TCF = RCF \times PACF$$

then $TCF_I =$

$$RCF_I \frac{\cos(\theta_2 + \beta)}{\cos\theta_2} = RCF_I \times PACF_I$$

Final Correction Factor (*FCF*)

The correction factor for the combined effects of ratio error and phase angle, where both current and potential transformers are used, is called the instrument transformer correction factor, sometimes called final correction factor (*FCF*). It is the factor by which the reading of a wattmeter or watthour meter, operated from the secondaries of both a current and a potential transformer, must be multiplied to correct the effect of ratio errors and phase displacement of the current and voltage due to the measuring apparatus. Final correction factor is also the per cent registration to which a watthour meter must be adjusted to correct for instrument transformer errors at the given load and power factor.

$$FCF = RCF_K \times PACF_K$$

It will be noted that since the final correction factors are the product of the correction factors for ratio error and phase displacement, the possibility exists of so balancing these two effects in the design of instrument transformers as to produce a minimum correction factor for a wide range of conditions of measurements.

DETERMINATION OF METER ADJUSTMENT TO COMPENSATE FOR TRANSFORMER ERRORS

The application of correction factors, for the exact determination of the percentage adjustment to be made to a watthour meter to compensate for transformer ratio error and phase angle, is generally considered unnecessary for instrument transformers of recent manufacture on routine installations.

For practical purposes, corrections may be applied when desired. Knowing the ratio error and phase angle of an instrument transformer, or set of instrument transformers, to be used with a watthour meter, a determination of the adjustment to be made to the meter may be obtained by reference to a chart such as is illustrated in Fig. 5-9.

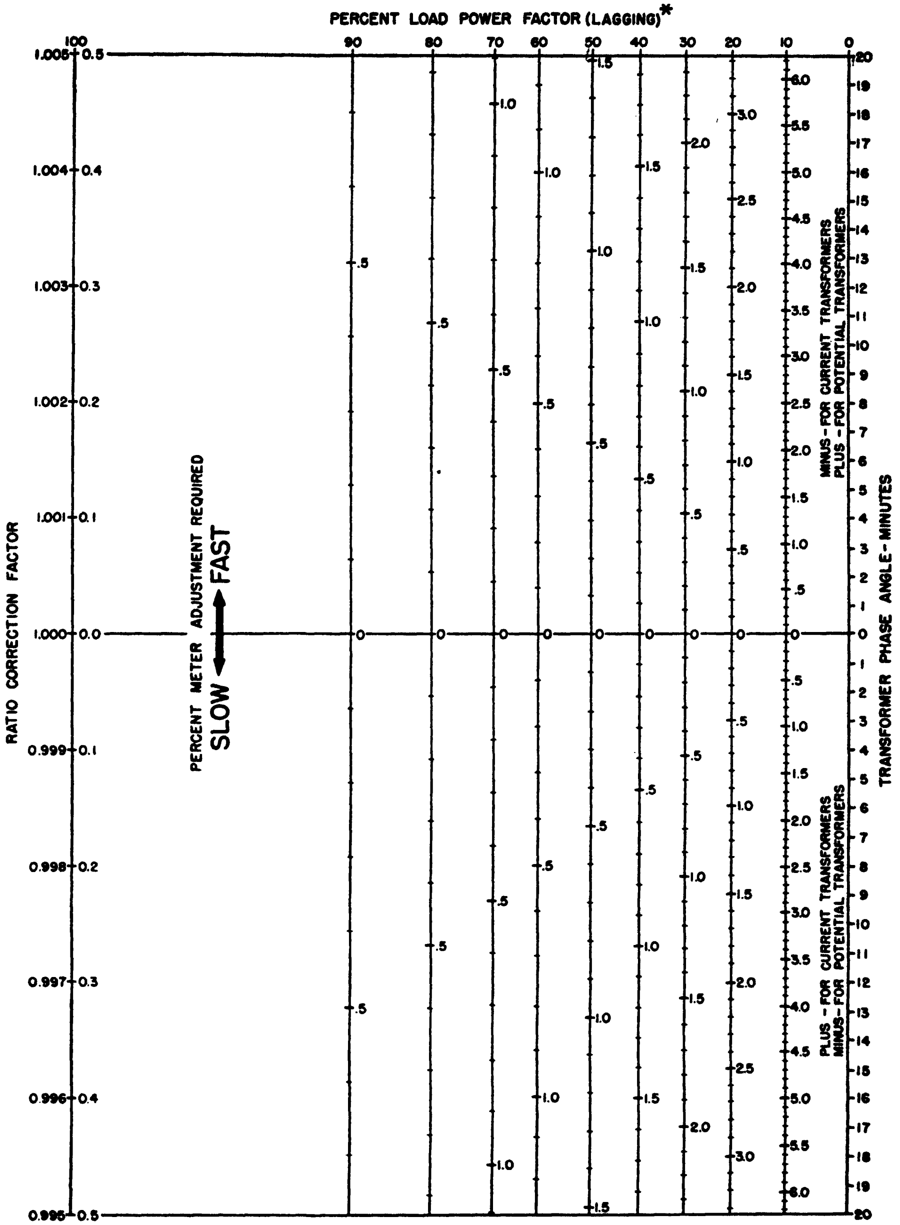


*CHART MAY BE USED FOR LEADING LOAD POWER FACTORS PROVIDED THE ALGEBRAIC SIGNS OF THE CURRENT AND POTENTIAL TRANSFORMER PHASE ANGLES ARE CONSIDERED AS REVERSED.

Fig. 5-9. Instrument Transformer Ratio and Phase Angle Chart

Instrument transformer certificates show the phase angle of the transformer in minutes, plus or minus. As to ratio, the certificate may show the "per cent of marked ratio," it may show true ratio, or it may give what is known as the "ratio correction factor." The ratio error and phase angle of a potential transformer will vary with the applied voltage, and the ratio error and phase angle of a current transformer will vary with the load current. For both types of transformers, the ratio error and phase angle will depend on the secondary burdens (instruments and meters) which are connected to the secondaries of the transformers. The certificate will indicate the secondary burden or burdens for which the indicated ratio error and phase angle is applicable, and these burdens will generally be what are known as ASA standard burdens for metering. Where the meter burden to be connected to the transformer secondary is not exactly equal to any one of the ASA standard secondary burdens, it is usually considered satisfactory to use the ratio error and phase angle corresponding to the nearest standard secondary burden.

Method 1

Current Transformers—If the "ratio correction factor" is not given on the certificate, it must be calculated from either of the formulas below for each of the two load points at which the watthour meter is to be adjusted.

$$\text{ratio c'r'n factor} = \frac{\text{true ratio}}{\text{marked ratio}}$$

$$\text{or ratio c'r'n factor} = \frac{\%\ \text{marked ratio}}{100}$$

Proceed to Fig. 5-9. Lay a straightedge across the chart so that it intersects the extreme left-hand vertical scale at the ratio correction factor determined for the transformer, and intersects the extreme right-hand vertical scale at the figure representing the phase angle of the transformer in minutes. Negative phase angle values are found above the center horizontal zero line and positive phase angle values below. Note where the straightedge crosses the vertical power factor lines in the center of the chart. Select the percentage power factor, lagging, which most closely represents the average power factor at which the meter will operate, and read the value on the line representing this power factor at the point where it is intersected by the straight-edge. The values found represent the percent adjustment which must be made to the meter in order to compensate for the ratio error and phase angle of the current transformer. If the value found is above the center horizontal line, the meter should be adjusted fast, and if the value found is below the center horizontal line, the meter should be adjusted slow.

This operation is repeated for each load point at which the watthour meter is to be adjusted.

For polyphase meters where more than one current transformer is involved, average the ratio correction factors and phase angles of the current transformers, and proceed exactly as described above, using the average figures.

Matching of Instrument Transformers—Where polyphase metering is involved, it is advisable to select sets of current transformers whose ratio errors and phase angles are nearly alike. However, where the ratio errors and phase angles of the current transformers are within ±0.5 per cent and ±20 minutes, respectively, no serious error will result in the determination or application of corrections. This same consideration applies to potential transformers.

Potential Transformers—The procedure for determining the per cent adjustment to compensate for potential transformer ratio error and phase angle is exactly the same as for current transformers, except that on the extreme right-hand scale, negative phase angle values are found below the center horizontal zero line, and positive phase angle values above.

Combined Current and Potential Transformers—Where both current and potential transformers are used,

TABLE 5-C
CALCULATION OF METER ACCURACY SETTINGS

Item	Symbol	Load		
		Light	Heavy	Inductive
		Power Factor 1.0		P.F. 0.5 lag
		10% Current	100% Current	
PHASE ANGLE (′)				
Current Transformer	β	+10	−2	−2
Potential Transformer	γ	+8	+8	+8
Combined	β-γ	+2	−10	−10
RATIO				
Current Transformer	*RCF*	1.004	0.999	0.999
Potential Transformer	*RCF*	0.998	0.998	0.998
Effect of Combined Phase Angle	*PACF*	1.000	1.000	1.005
By Addition		3.002	2.997	3.002
Subtract (No. of terms added minus 1)		2.	2.	2.
Final Correction Factor	*FCF*	1.002	0.997	1.002
Meter Accuracy Setting		100.2%	99.7%	100.2%

determine the average per cent adjustments separately for the current transformers and for the potential transformers, and add these average per cent adjustments algebraically, considering fast adjustments as plus, and slow adjustments as minus.

Method 2

Another method of determining the setting points of watthour meters is particularly useful where meter tests are made in accordance with a fixed routine, such as light load, full load and inductive load, made respectively at 10% and 100% rated current at power factor 1.0, and at 100% rated current and 0.5 power factor lagging. The method is applicable to installations with current and potential transformers, or either, and the calculations are simplified by using addition and subtraction for the multiplication of quantities near unity. Ratio and phase angle values are used directly, and the result is the accuracy performance to which the meter should be adjusted to compensate for instrument transformer errors. An example will make the method clear.

Assume that tests, or the test certificate of a current transformer, show its ratio correction factors and phase angles at meter burden to be 1.004 and +10 minutes at 10% current, and 0.999 and −2 minutes at 100% current. Similarly, the potential transformer test at normal voltage and burden shows a ratio correction factor of 0.998 and phase angle of +8 minutes. The data is summarized in Table 5-C.

In Table 5-C, "Effect of Combined Phase Angle" is determined from Table 5-B, (or 5-A if its sign were +). Where tests are made at a standard power factor, it is not necessary to use the table. At power factor 0.50 lagging, it can be determined from the table that for every minute of phase angle the correction factor changes by 0.0005 (0.05%). Thus it is only necessary to multiply the number of minutes of combined phase angle by 0.0005 to determine the correction. If the sign of the phase angle is − the result is added to 1.000. If the sign is + it is subtracted from 1.000. This is reversed if a meter setting point is required for leading power factor. Similarly, for power factors other than 0.50, the change per minute can be determined from the table. It is apparent that for 1.0 power factor the effect of phase angle is negligible throughout its practical range. Hence, if desired, the phase angle values need only be entered under "inductive load."

The same set-up may be used where only a current transformer or a potential transformer is used. It is only necessary to enter "0" under phase angle and "1.000" under ratio and make the additions and subtractions indicated.

For polyphase installations, the performance of the current transformers and of the potential transformers may be averaged, and the average values used for the calculations; or the calculations may be made on each element using the values for the transformers connected to that element.

INSTRUMENT TRANSFORMER BURDENS

Secondary Burden

The secondary burden of an instrument transformer is the load imposed on the secondary by meters, instruments, devices and wiring connected to the secondary circuit and may be expressed as ohms resistance and henrys inductance; as ohms impedance; or as volt-amperes at a specified power factor. To keep the effect of the load added by the secondary wiring small, it should be kept as short as practicable.

The secondary burdens of potential transformers are usually expressed in volt-amperes at a particular value of power factor, secondary voltage and frequency.

The secondary burdens of current transformers are usually expressed in ohms impedance at a particular frequency with the actual values of resistance and inductance given. At a particular frequency the inductance may be given in terms of reactance and, at a particular frequency and value of secondary current, the burden may be expressed in volt-amperes and power factor depending upon the relative values of resistance and reactance. Almost invariably the volt-ampere values are expressed on the basis of a 5-ampere secondary current.

Classification of Errors

It has been shown that errors depend both on burden and current or voltage, as well as on the properties of the transformer. Hence, any means of classification of transformers according to their errors must include a statement as to burden and current or voltage at which the error is measured.

The present American Standards for Transformers, ASA-C-57 specifies the standard instrument transformer burdens and accuracy classes.

An instrument transformer should be tested or its accuracy determined at one or more of the standard burdens, for normal use. However, where compensations for deviations introduced by the instrument transformers are to be computed, these determinations should be made at the approximate burden which will be imposed on the transformer under the particular conditions of measurement.

Current Transformer Burdens

When more than two instruments or meters together with the required wiring are connected in series with the secondary of a current transformer, the total burden is computed from the following equation:

$$\text{burden } (Z) = \sqrt{(\text{sum of resistances})^2 + (\text{sum of reactances})^2}$$

The volt-ampere burden on a current transformer is I^2Z. Burdens are usually computed at 5 amperes rated secondary current.

Where the burden is expressed in volt-amperes, the burden of each device and the burden of secondary conductors should be divided into in-phase and quadrature components and added.

$$\text{total } va = \sqrt{(\text{total watts})^2 + (\text{total vars})^2}$$

$$\text{in-phase } va \text{ or watts} = va \cos\theta$$

$$\text{quadrature } va \text{ or vars} = va \sin\theta$$

$$\text{power factor} = \cos\theta = \frac{\text{watts}}{va}$$

Potential Transformer Burdens

Secondary burdens of potential transformers are connected in parallel across the secondary of the transformer. The volt-ampere burden is equal to E^2/Z. If the burden is expressed as impedance in ohms, the total burden may be computed with sufficient accuracy by adding the admittances (reciprocals of impedances) and taking the reciprocal of the sum as the combined impedance. It is more convenient in general to determine the total output by adding the individual watts and vars and computing the resultant burden.

To calculate the total burden on the secondary of a transformer, the burden of each device should be divided into in-phase and quadrature components and added.

$$\text{total } va = \sqrt{(\text{total watts})^2 + (\text{total vars})^2}$$

$$\text{in-phase } va \text{ or watts} = va \cos\theta$$

$$\text{quadrature } va \text{ or vars} = va \sin\theta$$

$$\text{power factor} = \cos\theta = \frac{\text{watts}}{va}$$

Errors due to Secondary Wiring

Secondary conductors of potential transformers should be of such size as to limit the resulting errors due to voltage drop to a minimum. If the errors due to secondary conductors have not been compensated for, the ratio and phase angle corrections may be computed by using the following equations:

$$\text{ratio correction for conductors} = \frac{IR \text{ drop in wire} \times \cos\theta}{E_s}$$

where

E_s = potential transformer, secondary voltage

$\cos\theta$ = power factor of secondary burden

$$\text{phase displacement error } (\phi) = \sin^{-1} \frac{IR \text{ drop in wire} \times \sin\theta}{E_s}$$

The secondary conductors of current transformers are a part of the secondary burden and should be included in the calculation of the total burden.

The secondary conductors from a potential transformer do not add burden to the transformer but do affect the ratio and phase angle. Generally, these effects are small, but in some cases, e.g., if the conductors are long or the burden (va) is large, they may become of importance.

Polyphase Burdens

Instrument transformers used in metering polyphase circuits frequently have their secondaries interconnected in order to reduce wiring to a minimum. This interconnection is not desirable where the highest accuracy is demanded, but is sometimes necessary in practice. In such cases a complete and thorough analysis of actual burdens and conductor resistances must be made. The total burden may be determined by test, or by analysis made by one of three methods: by graphical solution, by analysis of complex quantities, or by vector and trigonometrical solution.

INSTRUMENT TRANSFORMER TYPES

Potential Transformers

Potential transformers are usually wound for some convenient integral value of the ratio of high tension applied voltage to the low tension terminal voltage as for example: 2400-120.

Potential transformers are usually wound for single ratio as indicated diagrammatically in Fig. 5-10a but may also be arranged for two ratios as shown in Fig. 5-10b. For the lower voltage, the two primary coils are connected in multiple as illustrated in the sketch. For the higher voltage the two primary coils are connected in series. Assuming that the transformer is designed for 7200 and 14,400 volts, the ratios would be 7200-120 and 14,400-120, respectively. Transformers of this type are not standard today, but for standard transformers in voltage ratings of 25 kv and above having reduced insulation at the neutral end and intended for grounded wye application only, a winding tap or a separate secondary winding is provided to give the rated secondary voltage with either a delta or wye secondary connection.

For special purposes, taps may be taken off at various points on the secondary winding as shown in Fig. 5-10c. While these taps are usually marked by a tag or otherwise, great care should be used in connecting such a transformer to be sure that the proper tap is used.

Autotransformers

An autotransformer, Fig. 5-10d, is one having only one coil, this having taps brought out at the proper points in the coil to give the voltages desired. Any portion of the coil may be used as the line voltage connection and any other portion as the load connection. The ratio of such a transformer is approximately

$$\frac{\text{line voltage}}{\text{load voltage}} = \frac{\text{number of turns used for line winding}}{\text{number of turns used for load winding}}$$

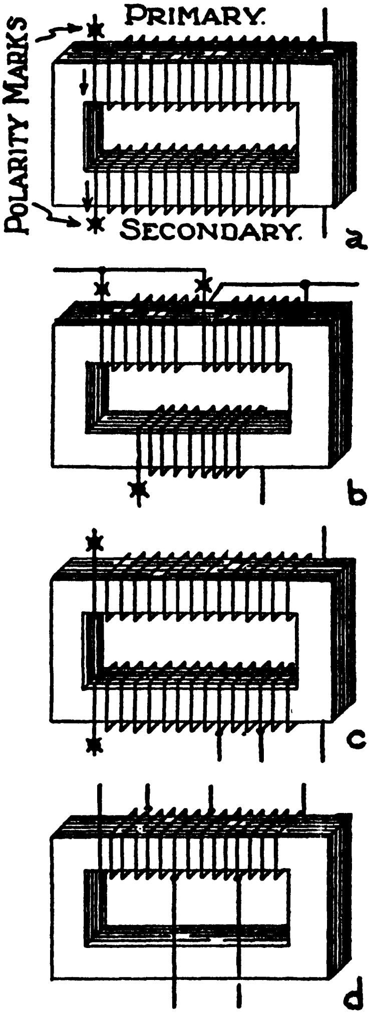


Fig. 5-10. Diagrammatic Representation of Potential Transformers

a—Single Ratio

b—Double Ratio

c—With Taps for Various Secondary Voltages

d—Autotransformer

Autotransformers are used for special purposes as in the phasing transformers used with varhour meters. See Section 3.

Three-Wire and Double-Ratio Current Transformers

A current transformer either of the type illustrated in Fig. 5-11a or the bus type shown in Fig. 5-11c may have the primary divided into two sections as shown in Fig. 5-11b. Such a transformer may be used as a double-ratio transformer. The principal advantage of such a transformer is obtained in high voltage metering where the capacity of the meter may be increased or decreased without changing the current transformer. A 200/400 ampere transformer, for instance, has a ratio of 200/5 when the primary coils are connected in series, and 400/5 when connected in multiple.

A double-winding-primary current transformer may be used for metering a three-wire, single-phase circuit using a two-wire watthour meter by connecting the primary windings in the circuit in a similar manner to the two current coils of a three-wire meter.

For the three-wire arrangement of Fig. 5-11b, the two line-side primary leads would be *a* and *d*, the corresponding load-side leads being *b* and *c* respectively. Such transformers are used on low voltage only, since it is difficult to provide the necessary insulation between the two primary windings. Two single-primary-winding current transformers can of course be used for metering three-wire, single-phase circuits, and this practice is the most common.

Window-Type Current Transformers

This type is similar in construction to the wound type except that the primary winding is eliminated, and an opening is provided through the core for the primary. Fig. 5-11c. A portable window-type current transformer is also available. By looping the primary conductor through the core, a number of different ratios may be obtained. For instance, if a transformer had a ratio of 1200/5 or 240/1 with a single turn, it would have a ratio of 120/1 with two turns, 80/1 with three turns, etc. In other words, the ratio

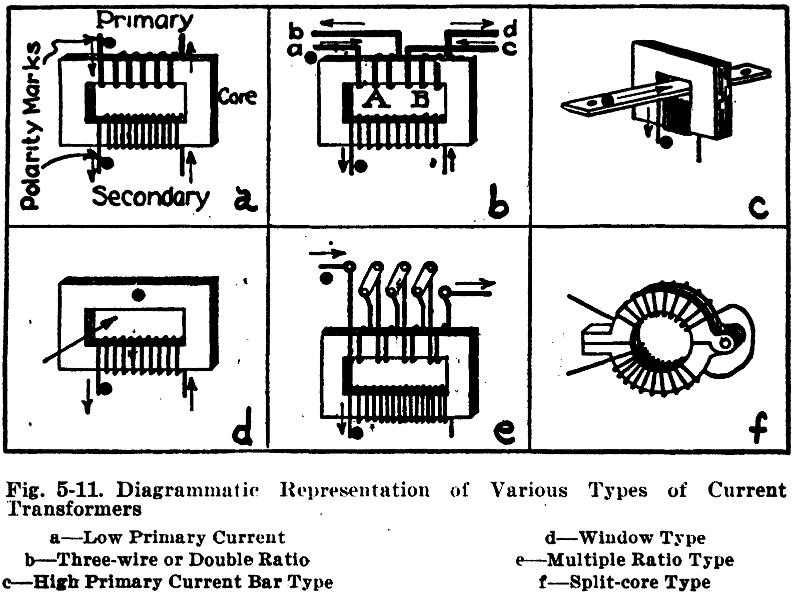


Fig. 5-11. Diagrammatic Representation of Various Types of Current Transformers

a—Low Primary Current
b—Three-wire or Double Ratio
c—High Primary Current Bar Type
d—Window Type
e—Multiple Ratio Type
f—Split-core Type

with any number of turns would be

$$\text{ratio} = \frac{\text{original ratio}}{\text{turns}}$$

The number of turns of the primary is the number of times the conductor passes through the hole in the core, and not the number of times the cable passes some point on the outside. Fig. 5-11d.

Multiple-Ratio Current Transformers

This type, illustrated in Fig. 5-11e, is similar to that illustrated in Fig. 5-11b except that it usually has a larger number of divisions of the primary coil, and facilities are provided by means of plugs or straps for series or multiple connections of the coils. The principal use is for laboratory and portable work. The connecting plugs or straps must be kept clean and in good mechanical condition.

Split-Core Type Current Transformers

This type, Fig. 5-11f, is similar to the "window" type shown in Fig. 5-11d except that the core consists of two hinged parts to facilitate its use on load-carrying conductors. The exciting current of this type of current transformer may be relatively large, and the losses and consequently the ratio error and phase angle may also be relatively large. It may not therefore be suitable for use with watthour meters but is a convenient device for portable use in current measurements. The surfaces of the core where the two halves join should be ample in area and make good mechanical contact. This type may have a multi-turn secondary with taps for obtaining different ratios.

There are available, however, precision designs similar to that shown in Fig. 5-15 which are being used for metering purposes with satisfactory results.

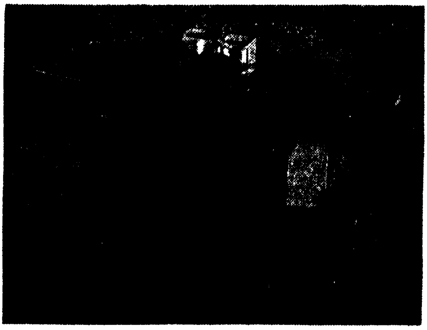
Representative Types

Representative types of instrument transformers are illustrated in Figs. 5-12 and 5-13.

Multi-Range Instrument Transformers

The inter-range accuracy or variation in ratio and phase angle between the various ranges of a multi-range instrument transformer of proper design is more or less independent of the characteristics of the magnetic core. Because of this fact, it is possible to make the inter-range accuracy very high and thereby obtain, by means of multi-range instrument transformers, from one accurately known value of amperes, volts, or watts, a great number of values of these units with practically equal accuracy. Figs. 5-14, 5-15, and 5-16 show some of these transformers.

Single Primary Single Secondary

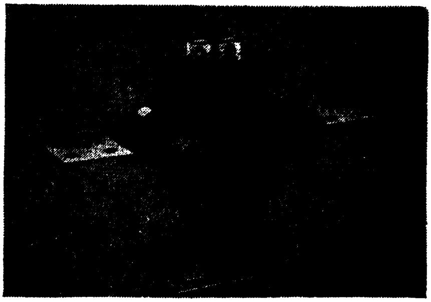


3-Wire

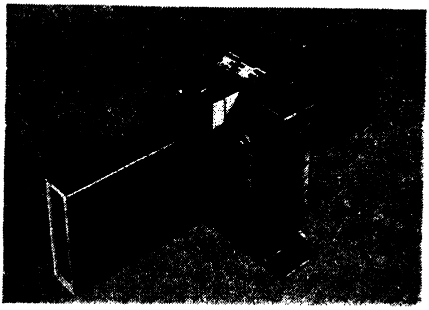
Fig. 5-12a. Typical Indoor Current Transformers for Metering Purposes

Indoor Transformers—Available in 2.5 to 15 Kv Insulation Classes

Single Primary Double Secondary

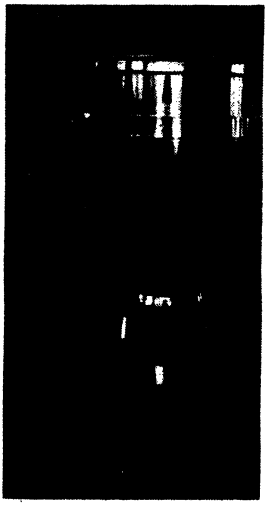


Bar Type

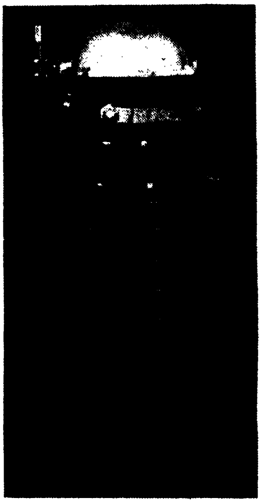


Window Type

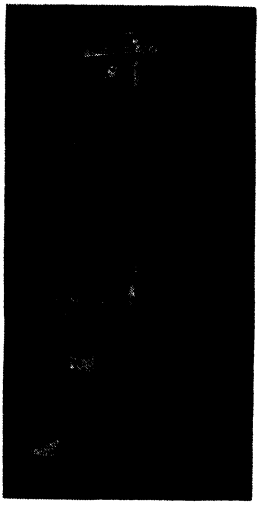
Outdoor Transformers—Available in all Insulation Classes



Wound Type 5-15 Kv

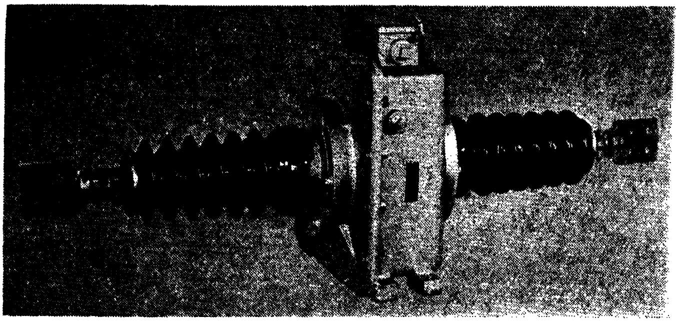


Wound Type 15-69 Kv

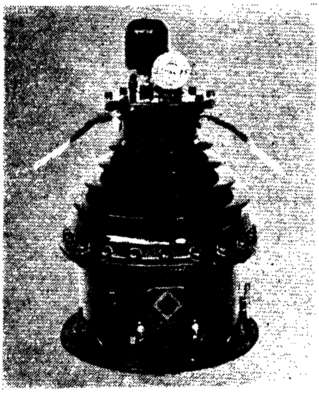


Wound Type 69 Kv and Up

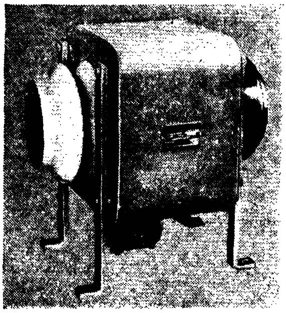
Fig. 5-12b. Typical Current Transformers for Metering Purposes



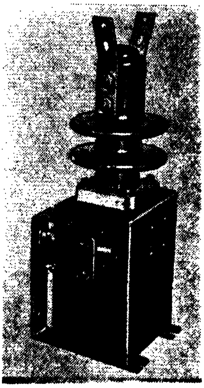
Bar Type 5-69 Kv



Wound Type 15-69 Kv



Window Type 5-69 Kv



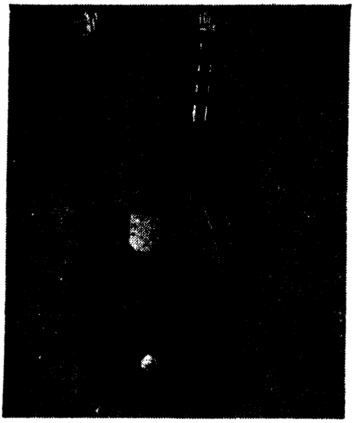
Wound Type 5-15 Kv

Fig. 5-12c. Typical Outdoor Current Transformers for Metering Purposes

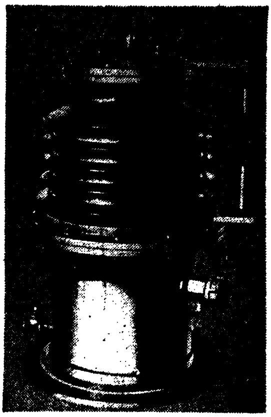
Indoor Type (Dry) 120V to 15Kv (Groups 1 & 2)

Outdoor Type (Compound) 5-15 Kv (Groups 1 & 2)

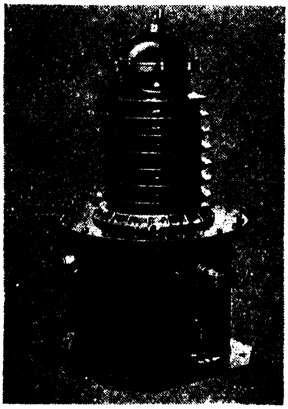
Fig. 5-13a. Typical Potential Transformers for Metering Purposes



Outdoor Type (Oil) 5-15 Kv (Group 1)

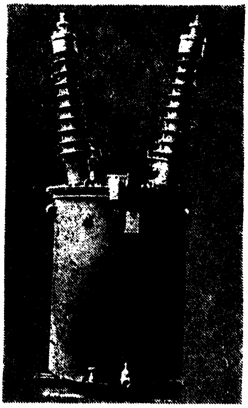


Outdoor Type (Liquid) 15-69 Kv (Group 3)

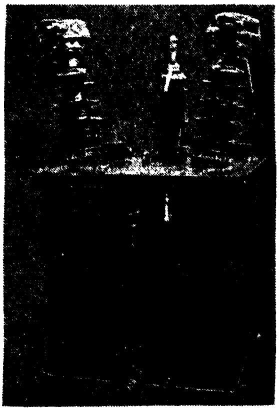


Outdoor Type (Liquid) 15-39 Kv (Group 3)

Outdoor Type (Liquid) 92 Kv and Up



Outdoor Type (Oil) 24 Kv and Up



Metering Outfit (Oil) 24 Kv and Up
2 Current and 2 Potential Transformers

Fig. 5-13b. Typical Potential Transformers and Metering Outfit

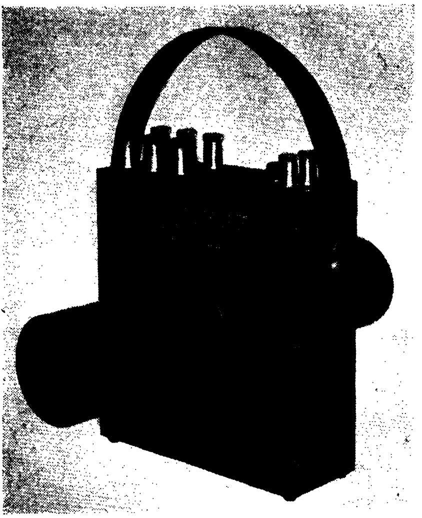


Fig. 5-14. Precision Multirange Current Transformer (Electrical Facilities, Inc.)

Through type rating for 16,500 volt circuits, 800, 1000, 1200, 1600 amperes. Self-contained rating for 2500 volt circuits, 5, 10, 20, 50, 100 amperes. Designed for precision current measurements on high voltage circuits. The high voltage bushing can be removed for low voltage work.

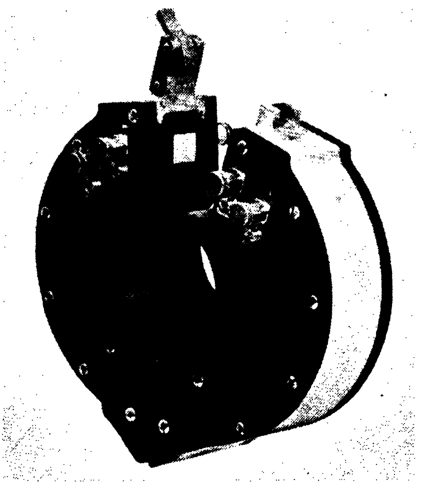


Fig. 5-15. Type SP-1000 Precision Split-Core Current Transformer (Electrical Facilities, Inc.)

Designed for overall testing of primary metering installations where current measuring devices cannot be inserted into the circuit. Rated for 5000 volt circuits, with 26 ranges from 5 to 1000 amperes.

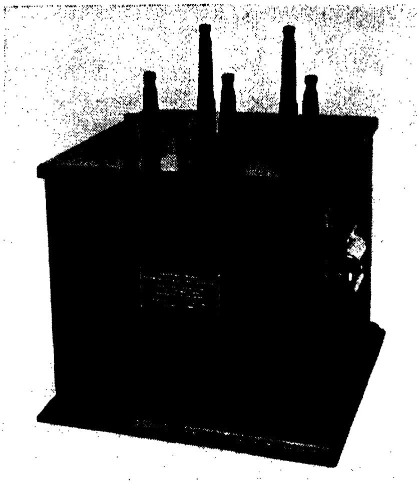


Fig. 5-16. Type SPT Precision Multirange Potential Transformer (Electrical Facilities, Inc.)

Designed as a Standard for Calibrating Potential Transformers for Ratio and Phase Angle of the Following Ratings: 120, 240, 480, 1200, 2400, 4800, 7200, 12,000, 14,400.

Knopp Uniload System

This system of multi-range load and measurement makes use of multi-range instrument transformers in such a manner that a single switching operation will suffice to obtain any desired value of current or potential within the scope of the equipment for application to an apparatus under test. At the same time connection is made to the corresponding primary range of a multi-range measuring transformer whose secondary current or potential is an exact measure of the test current or potential. Detailed descriptions of the application of this system to laboratory measurements are given in Section 12.

This uniload system may be used in the testing of ammeters, voltmeters, wattmeters, watthour meters, portable standard watthour meters, current transformers, and potential transformers.

GENERAL REQUIREMENTS FOR INSTRUMENT TRANSFORMERS

In addition to the requirement for ratio and phase angle accuracy necessary for instrument transformers when they are to be used in connection with watthour meters, the following should be given consideration in the selection of such transformers:

1. Insulation must be adequate to provide safety from breakdown between the primary and secondary windings. The insulation and construction must be such as to withstand a reasonable amount of handling without damage.
2. The mechanical construction of current transformers should be such as to prevent distortion of the core and windings due to surge currents.
3. As far as is consistent with good mechanical and electrical construction, the over-all dimensions between primary terminal bolt holes, the distance between terminals and plane of base, and the template drilling dimensions of the base of current transformers of similar types should be the same.
4. The arrangement of the secondary terminals or leads should be such that they are readily accessible, that they will not be damaged in handling, and that the connection with the secondary wiring will be secure.
5. Oil-insulated transformers should be so designed that the oil cannot leak or syphon through the leads.

Insulation Co-ordination

Insulation co-ordination is the proper proportioning of the insulation in the various parts of a system, considering the anticipated over-voltages which may occur. Co-ordination of insulation is generally accomplished by application of the following principles:

1. A consideration of the over-voltages that may appear on the system.
2. Construction of insulation strength into equipment as high as economically justified.
3. Provision of protective equipment to limit over-voltages to a definite value below the insulation strength of the equipment.

In practice, this results in building equipment to a definite insulation strength, above the voltage as limited by the protective devices.

Three things have been done with respect to instrument transformers in an attempt to accomplish co-ordination in practice: First, new standards have been accepted (and are generally being used) establishing definite insulation strengths for the various established circuit voltages and specifying the impulse and alternating-voltage power-frequency tests which the transformer shall be capable of withstanding; second, transformers are now being designed to meet these accepted standards; and third, better protective equipment (lightning arresters, by-pass protectors, lightning protector tubes, etc.) has been made available.

The present accepted standard for transformers, ASA-C-57, contains all this information, and parts are discussed under the heading, "Instrument Transformer Standards."

MAINTENANCE AND TESTING

Care in Handling

Care must be used in handling and storing instrument transformers so that the leads and terminals will not be damaged, or the insulation subjected to moisture.

Insulating Liquids

Oil or other insulating liquids are used in some instrument transformers. It is extremely important that the transformers be filled to the proper level, and that the insulating liquid be of the proper quality, and that it be kept free from dirt and moisture both while in service and in stock. Transformers stored for protracted lengths of time should have the oil checked before being placed in service.

Test Methods

Instrument transformers may be tested in conjunction with the watthour meters with which they are used (known as primary or "over-all" test), or the meter and transformers may be tested separately. When a primary test is made, the complete metering equipment, including meter and transformers, is tested as a unit.

The secondary testing method is generally used. It requires less complicated test equipment and provides a much greater safety factor for the testers. The secondary test method is as accurate as the primary test method when the instrument transformer has been tested with a secondary burden equal to that with which it will work, and from the record of such test, corrections, when necessary, are applied to the watthour meter under test. The performance of modern instrument transformers is such that corrections are not generally necessary. The following tests should be made on each instrument transformer:

Insulation
Polarity
Ratio
Phase Angle

Test for Insulation of Instrument Transformers

The insulation of instrument transformers must be adequate to protect the meters and control apparatus, as well as the operators and testers, from high voltage circuits, and to insure continuity of service. The insulation test should precede all the other tests.

The voltage test values for instrument transformers will be found in Tables 5-E and 5-F. It is not general practice to make impulse tests. Standards for such tests are specified in ASA-C-57, but they are intended primarily for design or acceptance test purposes when required. The alternating-current test (usually 60-cycle) can and should be made on each instrument transformer by the manufacturer. Common practice by users is to make these a-c tests on new transformers at slightly reduced values in order not to unnecessarily stress the insulation, usually at about 75% of the values given in the table. It is also common practice to make some such reduction of the test voltage applied to old transformers, usually to 75% or less of the table values.

Some protection is desirable in the high voltage circuit of testing transformers to prevent destructive surges and to limit the current if the transformer under test fails. If impedance in the form of choke coils is used in series with the high voltage terminals, it should be of such value that it will prevent damage to the test equipment.

When a spark gap is used, a non-inductive resistance of about one ohm per volt may be inserted in series with one terminal of the spark gap, to damp high frequency oscillations at the time of breakdown and limit the current flow. This resistance should be as near the gap as possible. If the test is made with one side grounded, this resistance should be on the ungrounded side of the circuit, and if neither side is grounded, the resistance should be inserted one-half on each side of the spark gap. Water tube resistors are preferable to carbon for this purpose, as the resistance of the carbon may be materially decreased by the passage of current.

All insulation tests for liquid-insulated transformers should be made with the transformer case properly filled.

Apparatus for A-C Insulation Test of Instrument Transformers—In making the a-c insulation test of an instrument transformer, any well-designed, high voltage transformer may be used as a source of supply. The transformer and the source of supply of energy should be not less than 2 kva for voltages of 50,000 volts or less and not less than 5 kva for voltages above 50,000 volts.

Control should be provided so that the test voltage taken from the transformer can be raised gradually. Full test voltage should not be applied instantaneously to the transformer under test.

The voltage may be measured by any approved method which gives root-mean-square values, preferably by means of a voltmeter connected to a special voltmeter coil in the testing transformer, or to a separate step-down potential transformer.

Test Voltage—Impulse and Low-Frequency Tests—In the ASA-C-57 standards for transformers, various circuit voltages commonly used are grouped into voltage classes, and a definite impulse test value and a low-frequency (60-cycle) test value are assigned to the equipment coming under each voltage class.

Application of Impulse—The standard impulse test consists of two applications of a chopped wave followed by one application of a full wave. The crest values of chopped waves are approximately 15% higher than those for full waves. Tests made periodically on samples of different types of transformers as they come through the factory will give reasonable assurance that the production transformers meet the specifications.

Wave Shape

Since a large variety of wave shapes of surges occur in service, it is impractical, if not impossible, to duplicate all the possibilities by test. Therefore, for purposes of testing and comparison, a standard wave has been specified. On the basis of available data, it is considered that a test with this wave will demonstrate the strength of apparatus for application purposes. For transformers, the wave is designated as a 1.5 × 40 microsecond wave, which is one that rises to crest voltage in $1\frac{1}{2}$ microseconds and decreases to $\frac{1}{2}$ value in 40 microseconds. The nominal 1.5 × 40 microsecond test wave is shown in Fig. 5-17.

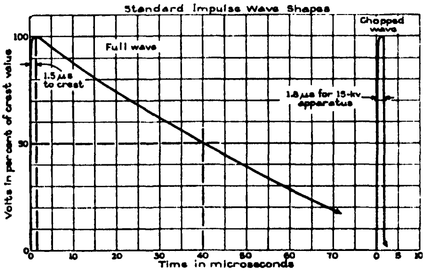


Fig. 5-17. Standard Impulse Wave Shapes

Polarity

The primary and secondary terminals of the transformers should be so

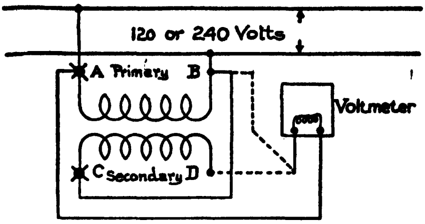


Fig. 5-18. Polarity Test—Voltage Measured from A to D is Greater Than Voltage from A to B if Polarity Markings are Correct

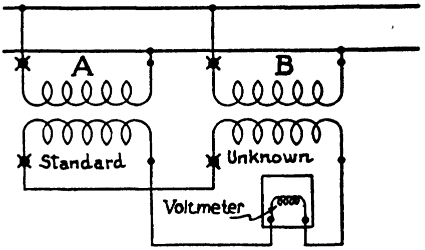


Fig. 5-19. Polarity Test—Voltage Measured Across Two Unmarked Terminals Equals Zero if Polarity Markings are Correct, Otherwise Measured Voltage is Twice Normal Secondary Voltage

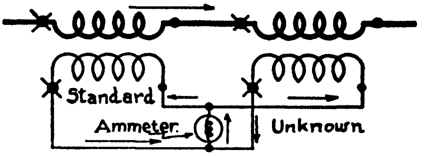


Fig. 5-20. Polarity Test—Current Measured by Ammeter is Twice Normal Secondary Current if Polarity Markings are Correct

An ammeter may be placed in the line instead of the standard transformer and the current differential noted when the marked secondary is connected to the line side of ammeter. An increased current indicates correct polarity markings.

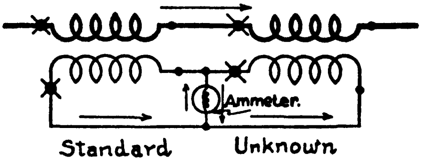


Fig. 5-21. Polarity Test—Ammeter Indicates Zero (or nearly so) if Polarity Markings are Correct

marked that when connection is made to a secondary terminal bearing the same marking as a given primary terminal, the polarity will be the same as if the primary conductor itself were detached from the transformer and connected directly to the secondary conductor, Figs. 5-10 and 5-11. This marking of the leads should be carefully checked by a polarity test. In most methods of checking transformers for ratio and phase angle the test connections are usually permanently and suitably arranged so that if the polarity markings of the transformer under test are correct, the meters will have proper indication. With proper precautions, this automatically checks the polarity of the transformer at the time of test. Figs. 5-18, 5-19, 5-20 and 5-21 illustrate some of the methods that may be used for testing the relative polarity of instrument transformers where such permanent test facilities are not available.

Testing of Instrument Transformers for Ratio and Phase Angle

Methods of testing instrument transformers may be generally classified into either direct or relative methods. In the direct methods the ratio error and phase angle are determined for the transformer under test by the use of indicating instruments and standard resistors, inductors, and capacitors. In the relative methods, the constants of the transformer under test are compared with those of a standard transformer, the characteristics of which have previously been determined by a direct method.

Both the direct and the relative methods may be of the deflectional or the null methods.

Direct methods are used in standardizing laboratories for the calibration of standards.

Relative methods are simpler and are generally employed for routine testing of instrument transformers. Direct methods applicable for rough field checks of instrument transformers are outlined briefly. The two relative methods generally employed for routine testing are described in detail.

Direct Methods of Testing—Current Transformers—Direct methods of precision current transformer tests generally employ standard resistors. The *IR* drop in each of two known noninductive resistors which carry the primary and secondary current respectively are adjusted so that they are equal and opposite. The ratio of currents equals the reciprocal of the ratio of resistances. The phase angle is determined from the value of inductance or capacity necessary to bring the two *IR* drops into exact phase opposition.

Diagrams of the test circuits, and illustrations of the arrangement of instruments, and a standard transformer as used by the U. S. Bureau of Standards are shown in Figs. 5-22, 5-23, 5-24 and 5-25.

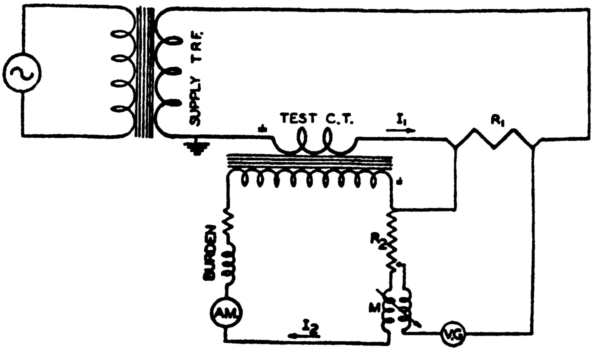


Fig. 5-22. Circuits Used in Direct Test of Current Transformer up to 2500 Amperes by the Resistance Method (National Bureau of Standards)

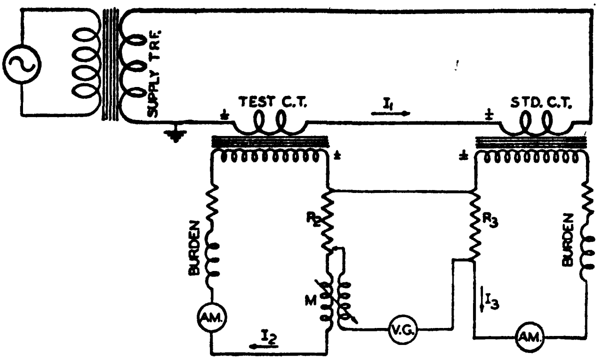


Fig. 5-23. Circuits Used in Testing Current Transformers of Over 2500 Ampere Rating by Comparison with the Standard Current Transformer (National Bureau of Standards)

Fig. 5-26 illustrates the wiring diagram of the Leeds and Northrup precision current transformer test set which compares the secondary current of the transformer under test with the drop produced by the primary current taken through a non-inductive shunt. Phase angle is balanced with a variable mutual inductance.

Potential Transformers — Resistance methods are generally applied to the direct determination of potential transformer constants. A high resistance non-inductive resistor is connected across the line which energizes the primary. The secondary voltage of the transformer is balanced against the voltage of a known portion of the resistor at its grounded end. The ratio of the transformer is then proportional to the ratio of the resistances. The phase angle is determined

Fig. 5-24. View of Equipment for Testing Current Transformers up to 12,000 Amperes (National Bureau of Standards)

S—Standard Current Transformer
O—Transformer Under Test
K—Supply Transformer
M—Tank Containing Oil-Cooled Standard Resistors

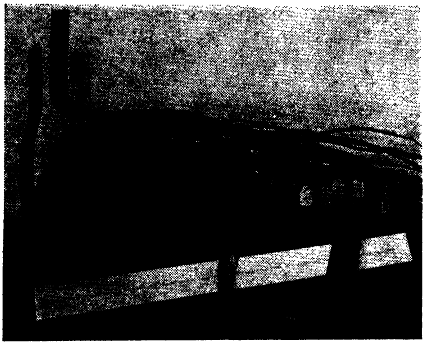


Fig. 5-25. Completed Wound Core of Standard Current Transformer Showing Secondary Winding and Two Primary Turns, One in Its Normal Position (National Bureau of Standards)

by balancing primary and secondary voltages through mutual inductance to exact phase opposition. Fig. 5-27 illustrates the wiring diagram of such potential transformer test equipment for ratings up to about 30,000 volts.

A second method of direct potential transformer test is by the balancing of capacitors, one being adjustable and of high capacitance and low voltage rating and the other of low capacitance and high voltage rating. This type of equipment is applicable to the testing of potential transformers with primary ratings above 30,000 volts. Fig. 5-28.

Two-Ammeter Method for Testing Current Transformers — For transformers of low current rating, the ratio is calculated from readings obtained with ammeters in the primary and secondary respectively, the quotient obtained by dividing primary amperes by secondary amperes being the ratio of transformation.

This method is applicable to test for ratio only and is subject to three general limitations:

1. Inherent errors in the instruments used.
2. The inability to obtain readings on the scales of ordinary instruments closer than 0.1 or 0.2 per cent.

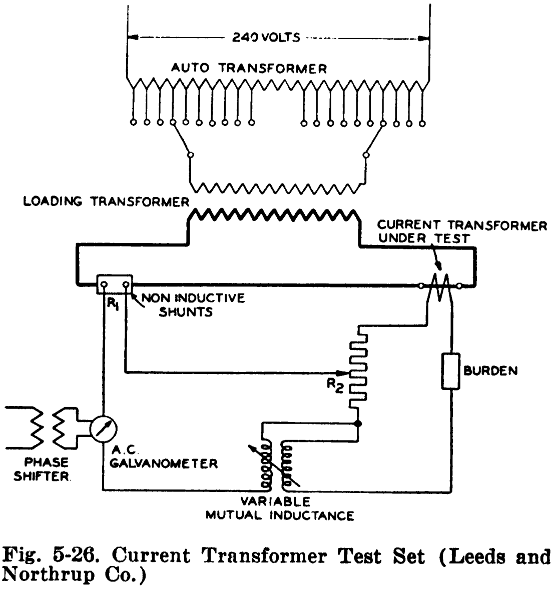


Fig. 5-26. Current Transformer Test Set (Leeds and Northrup Co.)

% Ratio $= 100 \times \frac{R_2}{R_1}$ Phase Angle in Minutes $= \frac{KM}{R_2} + P_s$

K = Constant
M = Mutual Inductance in Millihenries
P_s = Phase Angle of Primary Shunt

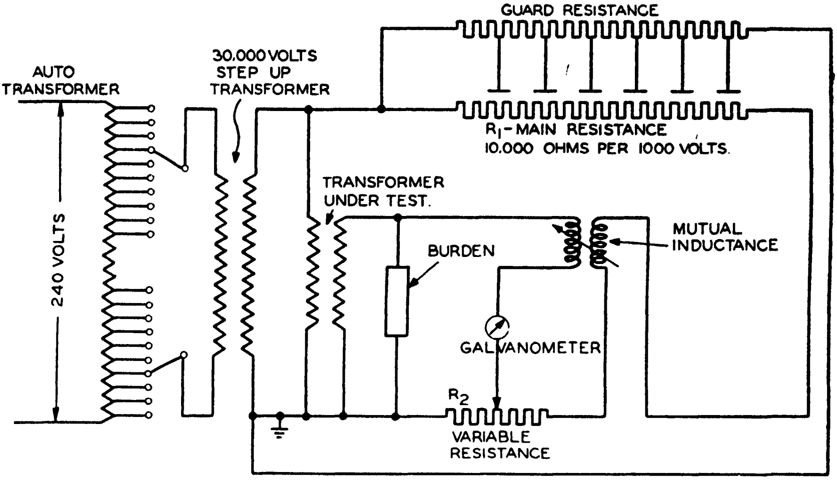
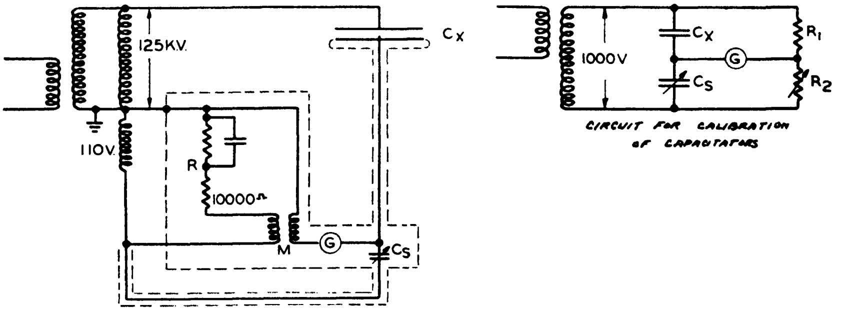


Fig. 5-27. Wiring Diagram, Leeds and Northrup Precision Potential Transformer Test Equipment, Primary Resistance Type

Ratio $= \frac{R_2}{R_1}$ Phase Angle $= \frac{KM}{R_2}$

K = Constant
M = Mutual Inductance

3. Scale readings on most alternating-current ammeters are good only in the upper half or two-thirds of their range, hence a change in instruments is necessary for obtaining ratio at light loads. Such a change in ammeters will ordinarily introduce greater impedance into the secondary circuit resulting in test inaccuracies.



Test Circuit

Circuit for calibration of capacitors

Fig. 5-28. Wiring Diagram, Leeds and Northrup Precision Potential Transformer Test Equipment, Primary Condenser Type

Ratio of Transformation $= \frac{C_s}{C_x} = \frac{R_2}{R_1}$

Phase Angle in Minutes $= \frac{\omega M}{R} \times 3438$

$\omega = 2\pi f$
M = Mutual Inductance
R = Total Resistance in Primary Circuits of Mutual Inductance
C_x = 125 Kv Air Condenser (Adjustable)
C_s = 3 Dial Mica Condenser
M = Brooks Inductometer Calibrated in Mutual Inductance
R = Compensating Box Containing Resistance to Limit Current From 110 Volt Secondary, and Means for Compensating for Inductance of Inductometer
G = Synchronous Commutator and D-C 2500 Galvanometer
R_2 = Resistance Box, 3 Dials (1 + 10 + 100) and 1.1 Ohm Slidewire
R_1 = 100,000 Ohm Fixed Noninductive Resistance to Stand 1000 Volts, 60 Cycles

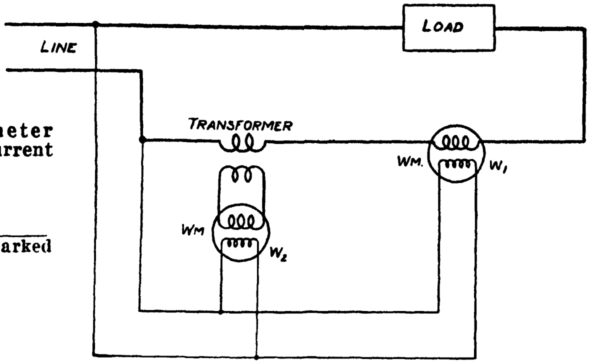


Fig. 5-29. Two Wattmeter Method of Testing Current Transformers

Ratio Correction Factor =

$$\frac{W_1}{W_2 \times \text{Ratio as Marked}}$$

$\theta = 90°$ Lagging

$$\cos(\theta \pm \beta) = \frac{W_2}{EI_2}$$

Two-Wattmeter Method for Testing Current Transformers—Comparison is made directly between readings of two wattmeters having their current coils in series with the primary and secondary, respectively, of the test transformer and their potential coils excited from a source in phase with the primary current. Fig. 5-29.

Phase angles may be measured with this method by using a source of voltage of known displacement from 60° to 90° out of phase with the supply current, the calculations of which are similar to those given in the two-watthour meter method.

The advantages of the wattmeter method as compared to the ammeter method are:

1. Wattmeter scales are much more uniform than ammeter scales, permitting fairly accurate reading to be taken on low ranges.
2. A wattmeter is given capacity will ordinarily have less impedance in its current circuit than an ammeter of the same capacity.
3. This permits the use of lower range instruments in testing without involving serious errors.
   The phase angle can be determined.

The limit of accuracy for the wattmeter method is determined principally by the accuracy of the wattmeters and the accuracy of reading.

The range of this method can be increased greatly by the use of a calibrated current transformer with the wattmeter in the primary circuit.

Two-Voltmeter Method for Testing Potential Transformers—There are two ways in which the indicating voltmeter method for testing potential transformers may be applied, depending upon the primary voltage of the transformers under test. Where the primary voltage is low, voltmeters connected to the primary and secondary circuits can be used and the ratio calculated by dividing primary voltage by secondary voltage, the secondary burden being varied between that required for voltmeter operation as a minimum and any desired maximum. Since the curves of ratio and phase angle for potential transformers are straight lines, values for zero burden can be obtained by extrapolation.

For primary voltages higher than 750, which is about the maximum for self-contained voltmeters, it is necessary to employ a second or standard transformer in making tests. The ratio is then determined as in the first method.

Voltmeters can be chosen of such a range as to bring the test readings within the best part of their scale. Hence, less trouble is experienced with instruments in testing potential transformers than in testing current transformers, and the limits of accuracy for this method are dependent upon the accuracy in the calibration of the instruments and accuracy of reading.

When testing a transformer by comparison with a standard transformer having the same nominal ratio, the voltage readings on the two instruments will be approximately the same,

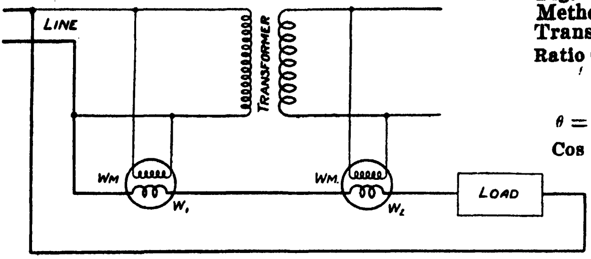


Fig. 5-30. Two Wattmeter Method of Testing Potential Transformers

Ratio Correction Factor =

$$\frac{W_1}{W_2 \times \text{Ratio as Marked}}$$

$\theta = 90°$ **Lagging**

$$\text{Cos } (90° \pm \gamma) = \frac{W_2}{E_2 I_2}$$

and instrument errors may be neutralized to a great extent by interchanging the instruments and averaging the readings.

Two-Wattmeter Method for Testing Potential Transformers—Wattmeters may be substituted for voltmeters in the testing of potential transformers; the two wattmeters in this case having a common current from the source in phase with the voltage of the transformers under test. Fig. 5-30.

Two-Watthour-Meter Method for Testing Instrument Transformers—The ratio and phase angle of instrument transformers may be readily and accurately determined by the use of two similar watthour meters or preferably two portable standard watthour meters, one meter connected to a standard transformer and the other to the transformer under test. The meters should be adjusted to register correctly at full load and light load, unity and low power factors, and should be of similar types. The accuracy of this method depends upon the accuracy of the ratio and phase angle curves of the standard transformers.

As the necessary meters and instruments are generally available in the meter department of even a small company, it is a convenient method for checking the ratio and phase angle when a limited number of transformers are to be tested. The principal objection to this method is the time required to obtain the necessary readings.

To test potential transformers, the voltage coil of one watthour meter is connected to the secondary of the standard transformer and the voltage coil of the other watthour meter to the secondary of the transformer to be tested. An auxiliary current is passed in series through the current coils of the two meters. A diagram of connections for testing a potential transformer by this method is shown in Fig. 5-31.

If the meters were adjusted to exactly the same accuracy, the ratios of the transformers would be inversely proportional to the number of revolutions of the meter disks in a given time. Practically, the meters cannot be adjusted to precisely the same accuracy, but the difference may be eliminated by interchanging the meters. One set of readings of the watthour meters is made with the meters connected as indicated above, and then another set of readings is taken with the meters interchanged by means of the double throw switches A and B. The difference in phase angles is obtained by changing the phase of the auxiliary current so that the meters are operating at low power factor. At low power factors the phase angle of the transformer causes an appreciable error in the watthour

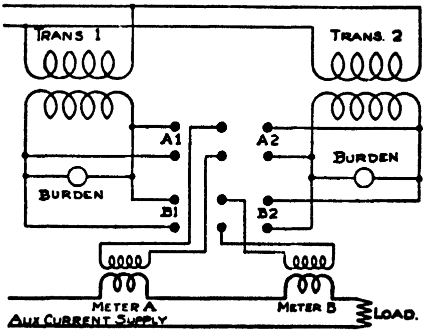


Fig. 5-31. Arrangement for Testing Potential Transformers. Watthour Meter Method

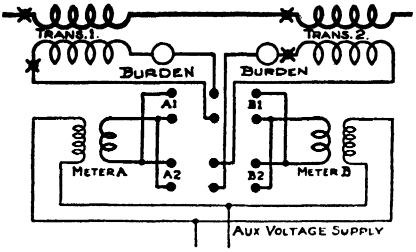


Fig. 5-32. Arrangement for Testing Current Transformers. Watthour Meter Method

meter accuracy as explained in the first part of this section. The meters will therefore run at different speeds if there is a phase-angle difference in the transformers.

The ratio test may be carried out with a single-phase source of supply, but for the phase-angle test a polyphase source or a phase shifter is necessary. With a three-phase source, the auxiliary current should be supplied from the same phase as the transformers for the ratio test and from the lagging phase for the phase-angle test. The meters should be interchanged for both the phase-angle and the ratio tests.

Fig. 5-32 shows the arrangement of circuits for testing current transformers. The primaries of the current transformers are connected in series, and the current coils of the two meters are connected alternately to the secondary circuits of the two transformers. An auxiliary voltage is applied to the potential coils of the meters connected in parallel. Otherwise the tests are carried out in the same way as for the potential transformer.

The watthour meter method, while not as rapid as the null method, with proper care gives results that are satisfactory as to accuracy.

The ratio test may be carried out with a single-phase source of supply, but for the phase-angle test a polyphase source or a phase shifter is necessary. With a three-phase source, the potential should be supplied from the same phase as the current loading circuit for the ratio test, and from the leading phase for the phase-angle test.

From these tests ratio and phase angle may be computed as follows:

Let R_1 = Ratio of standard transformer.
R_2 = Ratio of transformer under test.
γ_s = Phase angle of standard potential transformer.
γ = Phase angle of potential transformer under test.
β_s = Phase angle of standard current transformer.
β = Phase angle of current transformer under test.

γ, γ_s, β and β_s are to be considered as positive (+) when the reversed secondary voltage or current leads the respective primary voltage or current and negative (−) when the reversed secondary voltage or current lags behind the respective primary voltage or current.

a_1, b_1 = Revolutions of watthour meters A and B respectively at unity power factor in ratio test, when supplied from the secondary of the standard transformer.

a_2, b_2 = The same for secondary of the transformer under test.

A_1, B_1, A_2, B_2 = Same as above except taken at low power factor for phase-angle test.

$\cos\theta_2$ = Power factor of load as measured by watthour meter supplied from secondary of standard transformer.

$\cos\theta$ = Power factor of load as measured by watthour meter supplied from secondary of transformer under test.

δ_1 = Phase angle between the secondary voltages of the two potential transformers.

δ_2 = Phase angle between the secondary currents of the two current transformers.

$$\delta_1 = \gamma_s - \gamma$$

$$\delta_2 = \beta_s - \beta$$

Ratio Test, Potential or Current Transformers

$$R_2 = R_1 \sqrt{\frac{a_1 \times b_1}{a_2 \times b_2}} \qquad (1)$$

Phase-Angle Test, Potential or Current Transformers

$$\frac{\cos\theta}{\cos\theta_2} = \sqrt{\frac{A_2 \times B_2}{A_1 \times B_1}} \times \sqrt{\frac{a_1 \times b_1}{a_2 \times b_2}} \qquad (2)$$

Potential Transformers—Tables 5-A and 5-B give the values of $\frac{\cos\theta}{\cos\theta_2}$ corresponding to various values of $\theta_2 - \theta$ (designated in the tables as $\beta - \gamma$).

If the phase-angle tests have been made at lagging power factor, the sign of δ_1 is positive (+) for all values of $\frac{\cos\theta}{\cos\theta_2}$ greater than unity and negative (−) for all values less than unity. This is reversed if the tests have been made at leading power factors.

Current Transformers—In the same way as described above for potential transformers we may obtain the value of δ_2.

$$\beta = \beta_s - \delta_2 \qquad (4)$$

In the case of current transformers, if the phase-angle tests have been made at lagging power factor, the sign of δ_2 is negative (−) for all values of $\frac{\cos\theta}{\cos\theta_2}$ greater than unity, and positive (+) for all values less than unity. This is reversed if the tests have been made at leading power factor. *Particular regard must be paid to the respective signs in equations (3) and (4).*

Examples of Application of Method—*Readings obtained in test of a 2300/115 volt potential transformer:*

			REVOLUTIONS			
			Standard Transformer		*Transformer Under Test*	
	Volts	*P.F.*	a_1	b_1	a_2	b_2
Ratio Test	115.0	1.0	30.00			29.93
			30.01			29.93
				30.02	29.96	
				30.00	29.95	
Total			60.01	60.02	59.91	59.86
			A_1	B_1	A_2	B_2
Phase Angle Test	115.0	0.5		14.99	15.02	
				15.00	15.03	
			15.01			14.90
			15.00			14.90
Total			30.01	29.99	30.05	29.80

Standard Transformer Ratio $R_1 = 19.86$
Phase Angle $\gamma_s = +5'$

Since $\delta_1 = \gamma_s - \gamma = \theta_2 - \theta$, we may let $\beta - \gamma$ (the left-hand column) represent δ_1.

Find the value of $\frac{\cos\theta}{\cos\theta_2}$ obtained in equation (2), under the value of $\cos\theta_2$ (apparent power factor) used in the phase-angle test. On the same line at the left in column headed $\beta - \gamma$ is found the desired value of δ_1; then

$$\gamma = \gamma_s - \delta_1 \qquad (3)$$

Ratio

$$R_2 = R_1 \sqrt{\frac{a_1 \times b_1}{a_2 \times b_2}}$$

$$= 19.86 \sqrt{\frac{60.01 \times 60.02}{59.91 \times 59.86}}$$

$$= 19.86 \sqrt{\frac{3601.8}{3586.2}} = 19.86 \times 1.002$$

$$= \mathbf{19.90}$$

Phase Angle

$$\frac{\cos\theta}{\cos\theta_2} = \sqrt{\frac{A_2 \times B_2}{A_1 \times B_1}} \times \sqrt{\frac{a_1 \times b_1}{a_2 \times b_2}}$$

$$= \sqrt{\frac{30.05 \times 29.80}{30.01 \times 29.99}} \times \sqrt{\frac{60.01 \times 60.02}{59.91 \times 59.86}}$$

$$= .997 \times 1.002 = 0.999$$

Referring to Table 5-A, 0.999 is between 1.0000 and 0.9975 found in the column headed 0.50, apparent power factor cos θ_2.

The value of δ_1 at the left (headed $\beta - \gamma$) corresponding to 0.999 is 2′ (10/25 × 5′ = 2′)·

The instructions regarding sign of δ_1 given in equation (3) state that for lagging power factor when $\frac{\cos\theta}{\cos\theta_2}$ is less than unity δ_1 is negative, therefore $\delta_1 = -2'$

$$\gamma = \gamma_s - \delta_1$$
$$\gamma = 5' - (-2') = +7'$$

Phase Angle

$$\frac{\cos\theta}{\cos\theta_2} = \sqrt{\frac{A_2 \times B_2}{A_1 \times B_1}} \times \sqrt{\frac{a_1 \times b_1}{a_2 \times b_2}}$$

$$= \sqrt{\frac{40.09 \times 39.91}{40.00 \times 40.00}} \times \sqrt{\frac{59.99 \times 60.02}{59.84 \times 59.88}}$$

$$= 1.000 \times 1.002$$

$$= 1.002$$

Referring to Table 5-B, 1.002 is between 1.000 and 1.0025 found in the column headed 0.50 apparent power factor (cos θ_2). The value of δ_2 at the left ($\beta - \gamma$) corresponding to 1.002 is 4′. The instructions regarding the sign of δ_2 given with equation (4) state that for lagging power factor δ_2 is negative when $\frac{\cos\theta}{\cos\theta_2}$ is greater than unity, therefore,

$$\delta_2 = -4'$$
$$\beta = \beta_s - \delta_2$$
$$= -2' - (-4')$$
$$= +2'$$

Readings obtained in test of a 200/5 current transformer:

			Revolutions			
			Standard Transformer		*Transformer Under Test*	
	Sec. Amps.	*P.F.*	a_1	b_1	a_2	b_2
Ratio Test............	5.0	1.0	30.00			29.94
			29.99			29.94
				30.01	29.92	
				30.01	29.92	
Total.............			59.99	60.02	59.84	59.88
			A_1	B_1	A_2	B_2
Phase Angle Test.......	5.0	0.50	20.00			19.95
			20.00			19.96
				19.99	20.03	
				20.01	20.06	
Total.............			40.00	40.00	40.09	39.91

Standard Transformer Ratio, $R_1 = 39.82$

Phase Angle $\beta_s = -2'$

Ratio

$$R_2 = R_1 \sqrt{\frac{(a_1 \times b_1)}{(a_2 \times b_2)}}$$

$$= 39.82 \sqrt{\frac{59.99 \times 60.02}{59.84 \times 59.88}}$$

$$= 39.82 \times 1.002 = 39.90$$

Null Methods — Silsbee Current Transformer Testing Set—The Silsbee current transformer testing set is designed for use in routine testing of current transformers, either in the laboratory or in service.

The test set utilizes a comparison method in which the constants of the

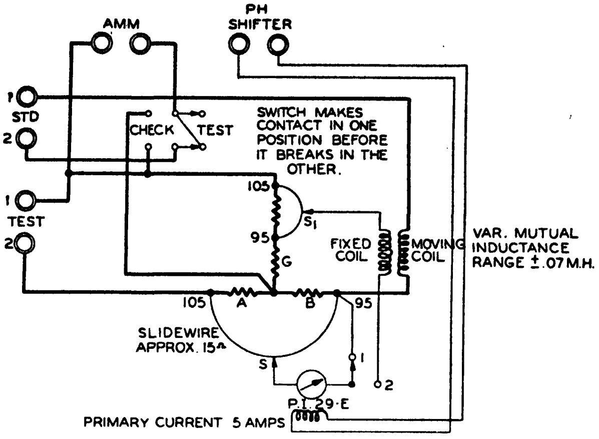


Fig. 5-33. Wiring Diagram of a Leeds and Northrup Silsbee Current Transformer Test Set. Dial of Slide S is Calibrated to Read % Ratio and S_1 to Read Phase Angle in Minutes

transformer being tested are determined by comparison with a calibrated transformer of the same nominal ratio. The secondaries of the transformers being compared are connected in series, and the detector is so connected that if both transformers had identical characteristics, no current would flow in the detector circuit. In general, the characteristics will be different and a differential current will flow in the detector circuit. If the phase and magnitude of this differential current are determined, the constants of one transformer can be measured in terms of the other. This differential current is measured by adjusting the impedance of a compensating circuit until all of the differential current flows through the compensating circuit instead of through the galvanometer. The adjustment of the compensating circuit is made by varying resistance and mutual inductance. The arrangement of circuits is such that the scale of the variable resistor can be calibrated directly in ratio values, and the scale of the mutual inductance can be calibrated to read in phase-angle values.

The detector is a separately excited electrodynamometer instrument supplied with potential from a phase shifting transformer and functions only as a zero current detector, hence utilizes the null method of test.

This arrangement has several advantages: first, the calibration of the set does not depend upon the calibration of the galvanometer used as the detector; second, contact resistances in the galvanometer circuit can cause no error; third, the possibility of errors due to stray fields is reduced to a minimum.

Permanency of calibration is an important feature of the Silsbee current transformer testing set. The calibration depends only upon the constancy of some resistors and a mutual inductance. Because a differential method is used, the resistance could vary by as much as 1 per cent without causing an appreciable error in the results. The calibration of the mutual inductance depends only upon its dimensions.

Fig. 5-33 is a wiring diagram of the set, and Fig. 5-34 the connection diagram.

Leeds & Northrup Potential Transformer Test Set—This test set is similar in design to the current transformer test set just described and utilizes the same phase shifter.

This testing set utilizes a null comparison method, and the transformer

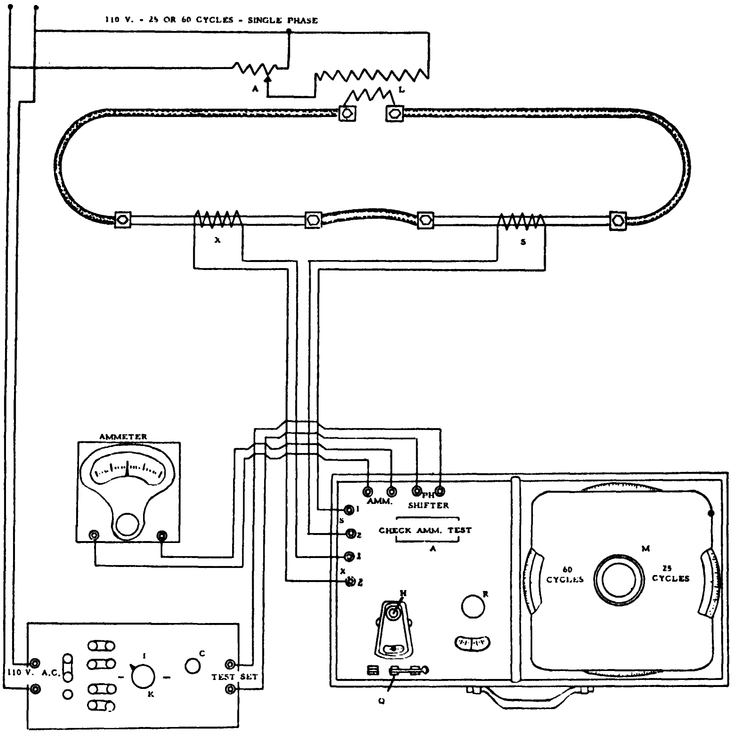


Fig. 5-34. Connection Diagram for Null Method (Silsbee) of Testing Current Transformers

under test is checked by comparison with a calibrated transformer. The test set has two scales, one reading directly in ratio values and the other in phase-angle values. Figs. 5-35 and 5-36 show a wiring diagram and method of connection.

In the potential transformer test set, the phase-angle adjustment is made with a calibrated mica condenser instead of the mutual inductance used in the current transformer test set.

There is no appreciable burden imposed on the transformer under test by the set, and accordingly, a transformer may be tested with its actual working burden without compensation for the burden of the set.

Knopp Uniload Current Transformer Test Set—The secondary of a precision multi-range current transformer is connected in series with the secondary of the transformer under test and to the current coil of a detector wattmeter. Fig. 5-37.

A single switch selects the proper current tap of the supply transformer and at the same time the proper range of the multi-range precision current transformer standard. A rheostat R_c permits the current to be regulated from 10 to 100 per cent of full load for each range. Ratio and phase-angle errors of the transformer under test can be determined from a consideration of the two detector wattmeter readings resulting when the differential current and two potentials of the same value, but displaced in phase from each other by 90 degrees, are applied and from the values of current in the secondary of the standard transformer and the potential applied to the detector. The multi-range standard can be calibrated in itself on the one-to-one range by comparing the primary current directly with the

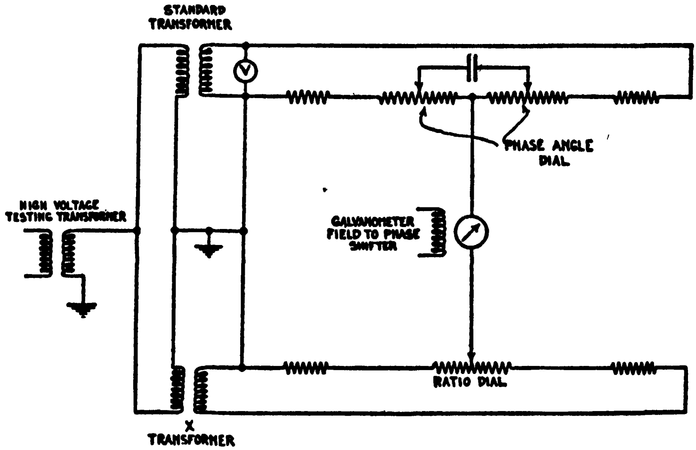

STANDARD TRANSFORMER
PHASE ANGLE DIAL
HIGH VOLTAGE TESTING TRANSFORMER
GALVANOMETER FIELD TO PHASE SHIFTER
RATIO DIAL
X TRANSFORMER

Fig. 5-35. Complete Diagram of Circuits for Portable Potential Transformer Testing Set (Leeds and Northrup Co.)

secondary current of this range merely by jumping out the transformer test position in the circuits. A rheostat R_p is provided to regulate the potential applied to the detector to an exact 100 or 200 volts.

The detector used is an especially designed wattmeter. The inaccuracies caused by the mutual inductance between current and potential coils as the pointer deflects over the scale are eliminated. When a wattmeter is used in the foregoing methods, it must be realized that the electromotive force in the current circuit is very small, particularly when current transformers of low ampere turn value are tested at zero burden. The electromotive force generated by induction in the current coil of the wattmeter from the potential or moving coil frequently may amount to an appreciable part of the first mentioned electromotive force, and, in exceptional cases, may exceed it, introducing large errors. These errors may be avoided by keeping the moving coil in a position of zero mutual inductance. This can be accomplished in a standard indicating wattmeter by using a torsion head

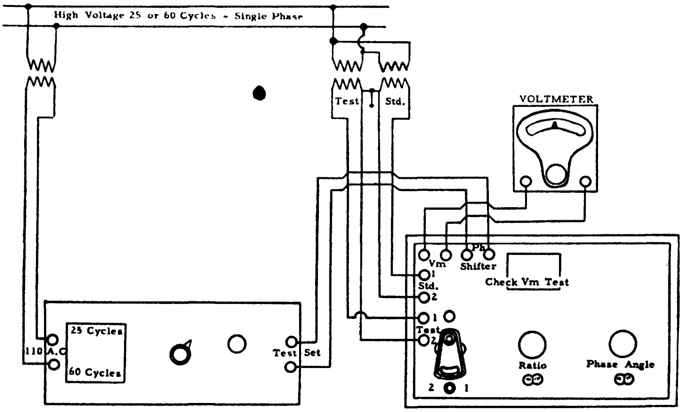


Fig. 5-36. Connection Diagram, Portable Potential Transformer Testing Set (Leeds and Northrup Co.)

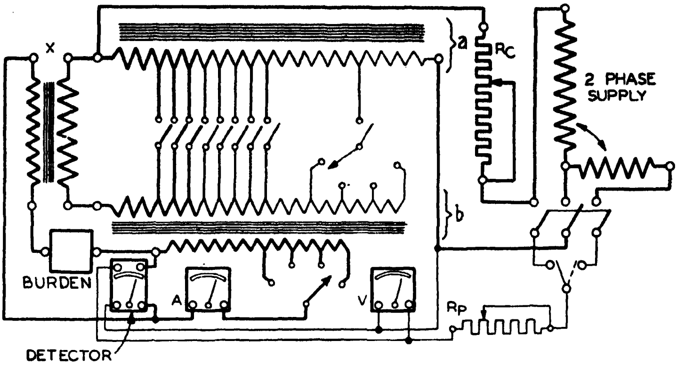


Fig. 5-37. Wiring Diagram of Knopp "Uniload" Type Current Transformer Testing Equipment

a—Supply Transformer
b—Measuring Transformer
Rc—Control Rheostat for Current
X—Transformer Under Test
Rp—Control Rheostat for Potential
A—Ammeter
V—Voltmeter
Detector—Special Wattmeter

attached to the zero adjuster and an additional pointer. The original indicating pointer is arranged so that in its zero position the moving coil is at right angles to the current coil system. By means of the torsion head the indicating pointer is kept at zero, and the torsion head pointer will indicate on a proportional scale the true wattage without the foregoing errors.

It is important to keep the resistance of both circuits of the wattmeter as low as possible and at the same time to provide high sensitivity. It is possible by using standard high-grade wattmeters for making up the detector, to obtain sensitivity sufficient to determine the ratios within 0.02 per cent and phase angles within 30 seconds. The detector is best built with zero in the center of the scale and then scaled directly in per cent ratio error and in phase angle, so that deflection of the pointer to the right represents high secondary output or leading phase angle, and to the left, low output and lagging angle.

A watt scale in addition to the other scales makes the detector wattmeter very useful as an indicating wattmeter for general laboratory work.

The Knopp type of potential transformer testing equipment using the so-called *uniload system* is similar to the current transformer equipment and is shown in Fig. 5-38. A multi-range precision type potential transformer is used as the standard and the transformer under test compared with it, as described under the similar current transformer testing equipment. The multi-range potential transformer, one of which is shown in Fig. 5-16, may also be calibrated by the one-to-one method previously described. The detector wattmeter is also the same as that previously described.

Two-Stage Transformer Tests—A method for testing two-stage current transformers using the Silsbee test set is illustrated in Fig. 5-39.

Stray Field Effects—In testing current transformers of large current rating, care should be exercised to shield the transformer from the effect of the stray field caused by the return primary conductor. One effective method used is to divide the return conductor into four sections, locating one section on each of the four sides of the transformer under test; another is to keep the return conductor at an effective distance from the transformer. If such care is not exercised, errors in test values may result.

Grounding of Instrument Transformer Secondaries and Cases

In general, the return or neutral conductors of the secondaries of instrument transformers and the cases and cores should be grounded. The

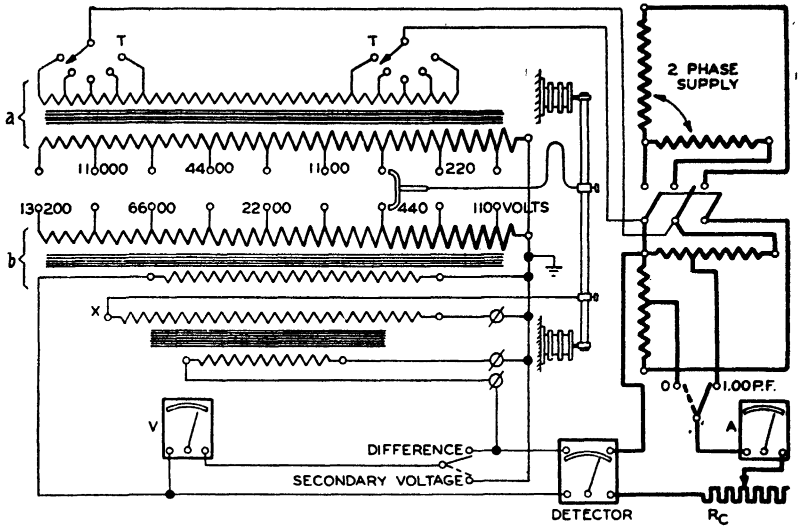


Fig. 5-38. Wiring Diagram and Component Parts Knopp "Uniload" Type Potential Transformer Testing Equipment

a—Potential Supply Transformer
X—Transformer Under Test
A—Ammeter
b—Measuring Transformer
T—Regulating Taps
V—Voltmeter
Rc—Current Control Rheostat
P.F.—Power Factor

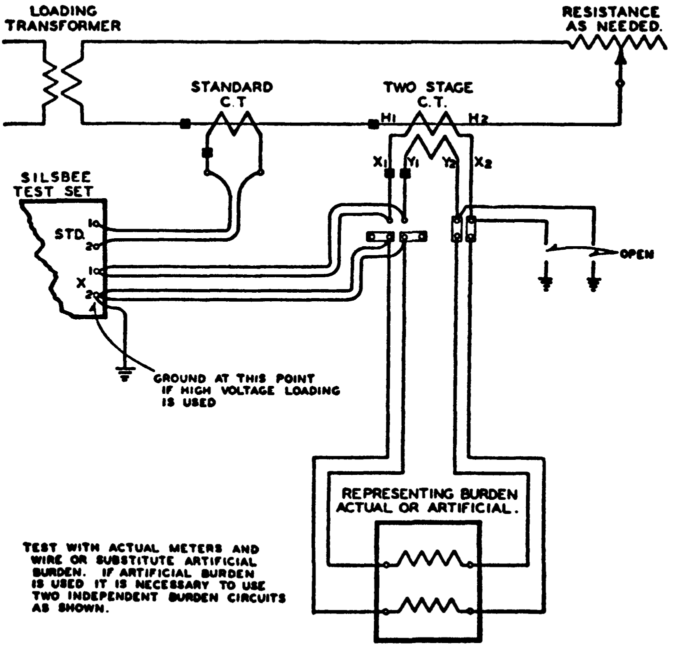

LOADING TRANSFORMER
RESISTANCE AS NEEDED.
STANDARD C.T
TWO STAGE C.T.
H1
H2
X1
Y1
Y2
X2
SILSBEE TEST SET
STD.
1
2
X
1
2
OPEN
GROUND AT THIS POINT IF HIGH VOLTAGE LOADING IS USED
REPRESENTING BURDEN ACTUAL OR ARTIFICIAL.
TEST WITH ACTUAL METERS AND WIRE OR SUBSTITUTE ARTIFICIAL BURDEN. IF ARTIFICIAL BURDEN IS USED IT IS NECESSARY TO USE TWO INDEPENDENT BURDEN CIRCUITS AS SHOWN.

Fig. 5-39. Connections for Testing Two Stage Current Transformers with Leeds and Northrup Silsbee Test Set

Auxiliary test leads should be of comparatively low resistance and should be paralleled only at terminals of test set. Ten feet of No. 10 or equivalent is satisfactory. Thorough inspection should be made on service tests to assure isolation between secondary and tertiary (X & Y) circuits. This is easily checked by removing Y circuit from set and ringing between X and Y.

secondaries should be grounded at one point only because of the possibility of stray ground currents in the secondary wiring if grounded at more than one place.

Generally, the grounding electrode should be common with that of any adjacent lightning arrester used to protect the transformers and the transformer grounding conductor run separately from that of the lightning arrester to this grounding electrode. The connection of the grounding conductor to the transformer secondaries should be close to the transformers.

Caution in Opening Secondary of Current Transformer

The secondary circuit of a current transformer should never be opened while the primary is carrying current. If it is necessary to disconnect instruments the secondary should first be short-circuited. If the secondary circuit is opened, a high voltage may be developed between terminals. This high voltage results when the secondary circuit is open because all of the primary ampere-turns are then effective in producing flux in the core. Normally but a very small portion of the total perform this function. The danger is magnified by the fact that the wave form of this secondary voltage is peaked, producing a high maximum value. A high flux produced in this way may also permanently change the magnetic condition of the core so that the accuracy of the transformer will be impaired.

The secondary terminals of a potential transformer should never be short-circuited. If they should become short-circuited, a heavy current will flow, which, if continued, will burn out the windings.

Checking Connections

In polyphase installations involving instrument transformers, it is relatively easy to introduce an error in the connections between the transformers and watthour meter, either by changing the phase relations or reversing the polarity of current or potential coils. Forward rotation of the watthour meter disk is not a positive indication of correct connections, and some other means must be adopted. Since wrong connections will introduce serious errors in registration, and watthour meters are, in general, used in connection with instrument transformers only on large and important installations, too much care cannot be given to this matter.

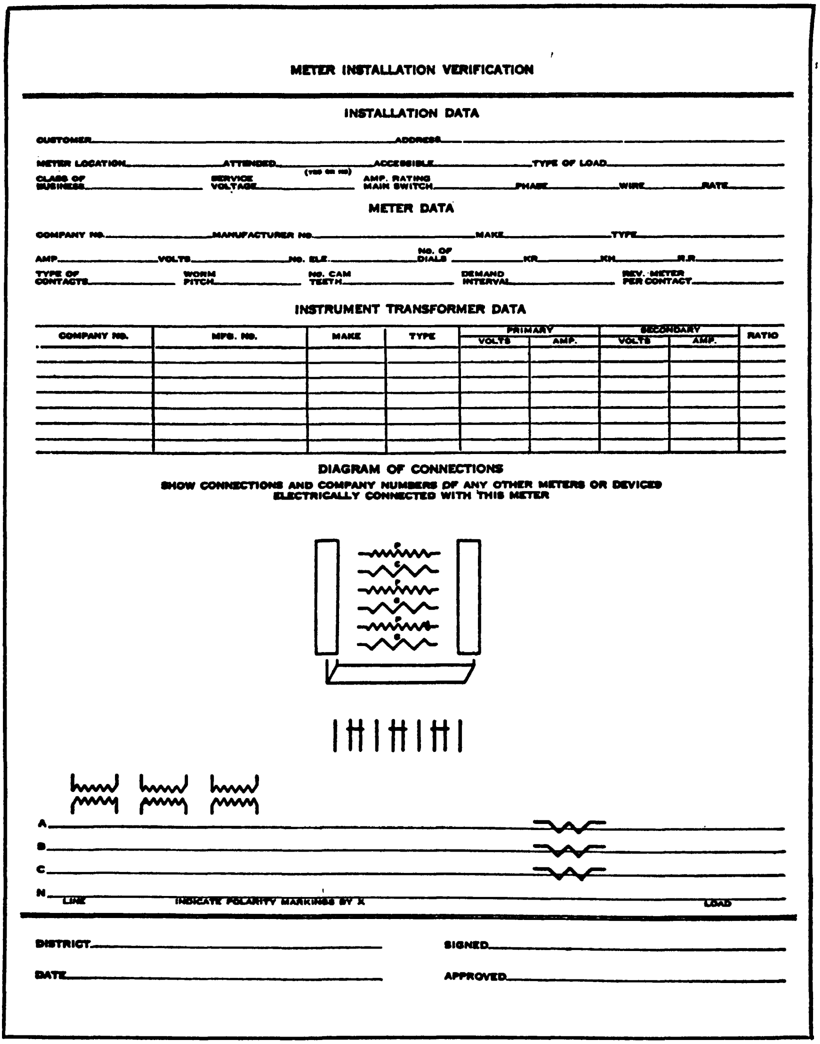
Methods for checking the connections of a polyphase watthour meter with instrument transformers may be divided into four general classes. First, by tracing the wiring and connections by some suitable means and comparing the results with the connection diagram supplied for the installation. Second, by changing the phase relations and noting the results on the watthour meter. Third, by making a primary test. Fourth, by verification of connections by comparison with indicating test instruments.

First Method—When colored identification wire is used in the secondary circuits, it is comparatively easy to identify the wires at any point for comparison with the connection diagram. In case colored identification is not used the procedure may be as follows:

Bridge the secondaries of the current transformers and disconnect each lead from the current and potential transformers and the meter. Then trace the secondary conductors by means of test lamps through an energy source or by means of a magneto or bell-and-battery device and identify each.

After the wires have been accurately identified at all connection points, the actual wiring of the installation is compared with the connection diagram. To aid in this, and as a record of the installation, some companies have adopted a chart or schematic skeleton diagram similar to that shown in Fig. 5-40. The inspector draws in the wiring as he finds it, and records the various meters, instruments, and transformers connected with the installation together with other pertinent information.

Second Method — The following method of checking the correctness



METER INSTALLATION VERIFICATION

INSTALLATION DATA

CUSTOMER________ ADDRESS________

METER LOCATION________ ATTENDED________ (YES OR NO) ACCESSIBLE________ TYPE OF LOAD________

CLASS OF BUSINESS________ SERVICE VOLTAGE________ AMP. RATING MAIN SWITCH________ PHASE________ WIRE________ RATE________

METER DATA

COMPANY NO.________ MANUFACTURER NO.________ MAKE________ TYPE________

AMP.________ VOLTS________ NO. ELE.________ NO. OF DIALS________ KR________ KH________ R.R.________

TYPE OF CONTACTS________ WORM PITCH________ NO. CAM TEETH________ DEMAND INTERVAL________ REV. METER PER CONTACT________

INSTRUMENT TRANSFORMER DATA

COMPANY NO.	MFG. NO.	MAKE	TYPE	PRIMARY		SECONDARY		RATIO
				VOLTS	AMP.	VOLTS	AMP.	

DIAGRAM OF CONNECTIONS

SHOW CONNECTIONS AND COMPANY NUMBERS OF ANY OTHER METERS OR DEVICES ELECTRICALLY CONNECTED WITH THIS METER

DISTRICT________ SIGNED________

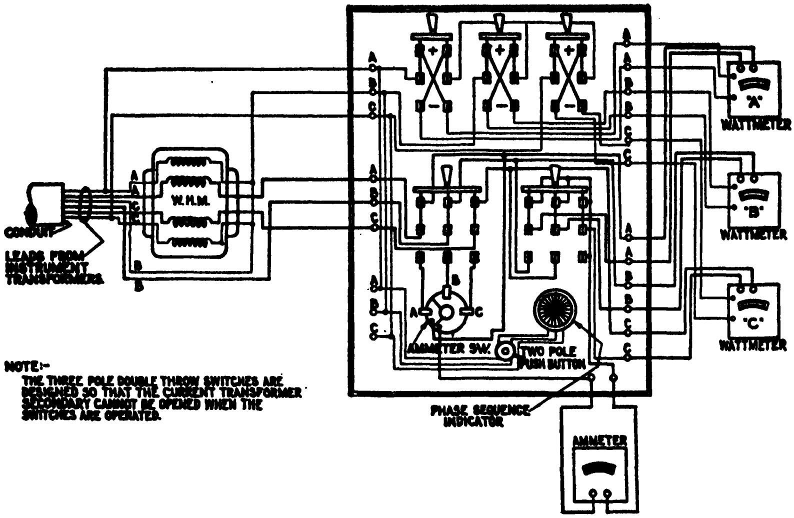
DATE________ APPROVED________

Fig. 5-40. Typical Form for Meter Installation Verification

of a two-element polyphase watthour meter used in connection with instrument transformers on a three-phase circuit by means of the interchange of voltage connections gives fairly reliable results if the load on the circuit is reasonably balanced. Having observed rotation in the proper direction, interchange the potential connections at the meter and if rotation ceases the original connections may be assumed correct, and should be restored.

Third Method—The overall accuracy test has operating limitations due to physical difficulties in connecting standard transformers in the circuit. Improvement in design and characteristics of modern instrument transformers have practically eliminated the necessity for over-all tests of transformer installations. Better accuracies with less effort can be obtained from secondary tests.

Fourth Method — Individual instru-



NOTE:-
THE THREE POLE DOUBLE THROW SWITCHES ARE DESIGNED SO THAT THE CURRENT TRANSFORMER SECONDARY CANNOT BE OPENED WHEN THE SWITCHES ARE OPERATED.

Fig. 5-41. Assembly of Apparatus for Circuit Connection Verification

ments connected into the secondary metering circuits may be used to get data necessary to construct vector diagrams showing the load conditions as measured by the service metering equipment. An assembly of instruments for such a test is shown in Fig. 5-41.

Three wattmeters may be connected to the three-phase lines, with current coils in each line and potential coils connected in wye from each phase to a common point; the sum of the three wattmeter readings equals the total power of the circuit and can be used to check the watthour meter. Fig. 5-42.

In the vector diagram, Fig. 5-43, the vector I_1 represents the current in line one and has a true power projection on vector V_{10} of *oa* which is proportional to the measured power of wattmeter 1. If wattmeter 2 were so connected that the current I_1 energized the current coil and voltage V_{20} energized its potential coil, the indicated wattmeter reading would be proportional to the true power projection of I_1 on V_{20} or to *ob* in the diagram. Similarly, wattmeter 3 could measure the projection *oc* from the indication of I_1 and V_{30}. Perpendiculars constructed from points *a*, *b*, and *c* derived from these readings meet at a point, fixing the position and magnitude of I_1. The current vectors of the

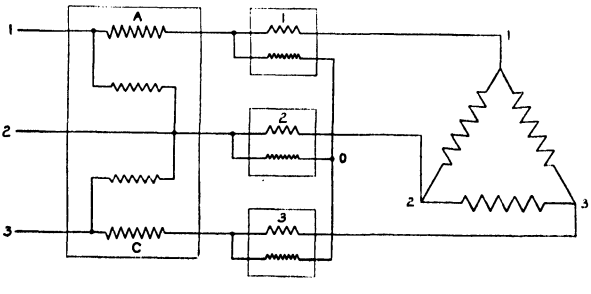


Fig. 5-42. Three Wattmeter Connection to Verify Watthour Meter Connections

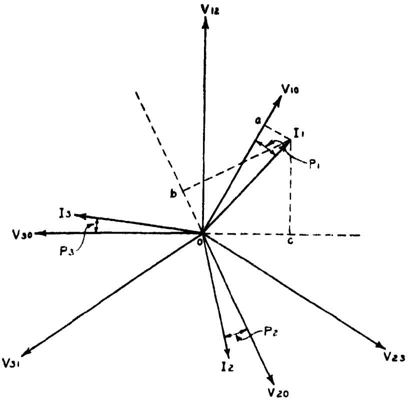


Fig. 5-43. Vector Diagram for Meter Verification

other two phases may similarly be determined. The completed vector diagram of metered currents related to true phase positions of metered voltage may be thus reproduced.

The same principle may be used to make connection verification by means of a stop watch if the load conditions are fairly steady. By the use of jumpers on the test switch, time checks of I_1 with V_{12} and I_1 with V_{32} may be made. These values plotted to scale along the voltage vectors and perpendiculars erected will give the position and magnitude of I_1. Similarly I_3 may be located. Fig. 5-44.

An analysis of the results obtained proves the correctness of the meter and transformer connections.

A picture of the primary conditions as recorded by the watthour meter is reproduced in the form of a vector diagram, and an analysis will reveal discrepancies caused by erroneous connections, defective load apparatus, grounds, etc.

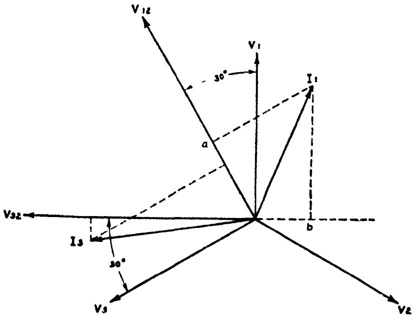


Fig. 5-44. Vector Diagram—Meter Verification by Timing Disk Rotation

Current Transformer Checking by Heavy Burden

An important detail of the verification test is the loading of the current transformer secondary with an impedor within the maximum burden rating of the transformer but of sufficient size to affect the ratio accuracies of the current transformers if short-circuited windings or grounds have developed. Short circuits or grounds which will affect the watthour meter accuracies by as little as one per cent will produce changes of 40% or more in the readings of one or more wattmeters.

A condition test of the transformers and secondary leads by the use of an impedor may be made whether the other tests described under this method are made or not. The effect of an impedor inserted in the secondary circuit of a defective transformer is apparent on the speed of rotation of a standard watthour meter disk.

INSTRUMENT TRANSFORMER STANDARDS

Dealing with instrument transformers there are a number of industry standards that have met with wide acceptance.

The primary standard generally used to classify ratings and performance of instrument transformers is the American Standards Association publication C-57. It is in three divisions, C-57.1 comprising the standards for instrument transformers, C-57.2 the test code, and C-57.3 the guides for their operation.

There are several other recommended specifications for standards that have been promulgated jointly by the Meter and Service Committee of the Edison Electric Institute and the Committee on Metering and Service Methods of the Association of Edison Illuminating Companies. These deal with details of design to bring about the uniformity of dimensions

TABLE NO. 5-D

STANDARD PRIMARY CURRENT RATING AND STANDARD RATIOS FOR CURRENT TRANSFORMERS

A—Single-Ratio Current Transformers

Standard Primary Current Rating	Standard Ratio	Standard Primary Current Rating	Standard Ratio	Standard Primary Current Rating	Standard Ratio
10	2:1	100	20.1	800	160:1
15	3:1	150	30:1	1200	240:1
25	5:1	200	40:1	1500	300:1
40	8:1	300	60:1	2000	400:1
50	10:1	400	80:1	3000	600:1
75	15:1	600	120:1	4000	800:1

B—Double-Ratio Current Transformers

Standard Primary Current Rating	Standard Ratio	Standard Primary Current Rating	Standard Ratio
25/50	5/10:1	200/400	40/80:1
50/100	10/20:1	400/800	80/160:1
100/200	20/40:1	600/1200	120/240:1

and ratings that is most desirable. They are published by the Edison Electric Institute.

EEI Publication MS-2, is the *Specifications for Coordinated and Standardized Low Voltage Metering Current Transformers,* and MS-3 is the *Specifications for Standard Current Transformers for Primary Circuits.* Further specifications are in preparation.

SOME PROVISIONS OF ASA STANDARD C-57

Terms in Which Ratings Shall be Expressed

Current Transformers: The rating of a current transformer shall include ratio in terms of primary and secondary currents; continuous thermal current rating factor; insulation class and impulse level in terms of full wave test voltage; frequency; standard accuracy classes at specified standard burdens, current and frequency; together with the short time thermal and short time mechanical current ratings.

Potential Transformers: The rating of a potential transformer shall include rated primary voltage and ratio; insulation class and impulse level in terms of full wave test voltage; frequency; standard accuracy classes at specified standard burdens, voltage and frequency; together with continuous output in volt-amperes (thermal burden rating).

Standard Ratings

Current Transformers

Standard ratios, see Table 5-D.

Standard insulation classes, see Table 5-E.

Potential Transformers

Standard ratios, standard insu-

TABLE 5-E

STANDARD INSULATION CLASSES AND STANDARD DIELECTRIC TESTS FOR CURRENT TRANSFORMERS

Standard Insulation Class (Name Plate Rating)	Maximum Line-to-Line Voltage	Standard Dielectric Tests			
		Std. Low Frequency Tests	Standard Impulse Tests		
			Chopped Wave		Full Wave
				Minimum Time to Flashover	
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6
Kv	Kv	Kv rms	Kv crest	μ sec	Kv crest
1.2	1.2	10	36	1.0	30
2.5	2.5	15	54	1.25	45
5.0	5.0	19	69	1.5	60
8.7	8.66	26	88	1.6	75
15 L	15	34	110	1.8	95
15 H	15	34	130	2.0	110
25	25	50	175	3.0	150
34.5	34.5	70	230	3.0	200
46	46	95	290	3.0	250
69	69	140	400	3.0	350
92	92	185	520	3.0	450
115	115	230	630	3.0	550
138	138	275	750	3.0	650
161	161	325	865	3.0	750
196	196	395	1035	3.0	900
230	230	460	1210	3.0	1050
287	287	575	1500	3.0	1300
345	345	690	1785	3.0	1550

lation classes and standard primary voltage ratings, see Table 5-F.

Potential transformers are divided into groups as follows:

Group 1—Designed for operation line-to-line, line-to-ground, or line-to-neutral, provided the line-to-neutral volttage does not exceed 1.25 times rated line-to-neutral voltage under emergency conditions.

Group 2—Designed for operation line-to-line. They may be operated line-to-ground or line-to-neutral at reduced voltage if this voltage does not exceed the transformer primary voltage divided by $\sqrt{3}$.

Group 3—Designed for operation line-to-ground only and suitable for either grounded or ungrounded systems.

The primary voltage rating, column 3 of Table 5-F, lists two values, one to indicate the primary winding voltage and the other to indicate the maximum three-phase circuit voltage when

TABLE 5-F

STANDARD INSULATION CLASSES, STANDARD MARKED RATIOS, STANDARD PRIMARY VOLTAGE RATINGS AND STANDARD DIELECTRIC TESTS FOR POTENTIAL TRANSFORMERS

Name Plate Marking			Usual Circuit Voltage	Permissible Transformer Connection	Standard Dielectric Tests			
Standard Insulation Class	Standard Marked Ratio	Standard Primary Voltage Ratings			Standard Low Frequency Test	Standard Impulse Test		
						Chopped Wave		Full Wave
						Crest Voltage	Min. Time to Flashover	
Column 1 Kv	Column 2	Column 3 Volts	Column 4 Volts	Column 5	Column 6 Kv rms	Column 7 Kv Crest	Column 8 μ Sec	Column 9 Kv Crest
GROUP 1—1.2 to 15 Kv—Full Insulation—Y Voltage Limit Equals √3 Times Δ Voltage Limit								
1.2	1:1	120/208Y	120 208	Δ or Y Y only	10	36	1.0	30
	2:1	240/416Y	240 416	Δ or Y Y only	10	36	1.0	30
	4:1	480/832Y	480 832	Δ or Y Y only	10	36	1.0	30
	5:1	600/1040Y	600 1040	Δ or Y Y only	10	36	1.0	30
5.0	20:1	2400/4160Y	2400 4160	Δ or Y Y only	19	69	1.5	60
8.7	35:1	4200/7280Y	4200 7280	Δ or Y Y only	26	88	1.6	75
	40:1	4800/8320Y	4800 8320	Δ or Y Y only	26	88	1.6	75
15 L	60:1	7200/12470Y	7200 12470	Δ or Y Y only	34	110	1.8	95
	70:1	8400/14560Y	8400 14560	Δ or Y Y only	34	110	1.8	95
15 H	60:1	7200/12470Y	7200 12470	Δ or Y Y only	34	130	2.0	110
	70:1	8400/14560Y	8400 14560	Δ or Y Y only	34	130	2.0	110

GROUP 2—2.5 to 345 Kv—Full Insulation—Y Voltage Limit Equals Δ Voltage Limit								
2.5	20:1	2400/2400Y	2400	Δ or Y	15	54	1.25	45
5.0	40:1	4800/4800Y	4800	Δ or Y	19	69	1.5	60
8.7	60:1	7200/7200Y	7200	Δ or Y	26	88	1.6	75
15 L	100:1	12000/12000Y	12000	Δ or Y	34	110	1.8	95
	120:1	14400/14400Y	14400	Δ or Y	34	110	1.8	95
15 H	100:1	12000/12000Y	12000	Δ or Y	34	130	2.0	110
	120:1	14400/14400Y	14400	Δ or Y	34	130	2.0	110
25	200:1	24000/24000Y	24000	Δ or Y	50	175	3.0	150
34.5	300:1	34500/34500Y	34500	Δ or Y	70	230	3.0	200
46	400:1	46000/46000Y	46000	Δ or Y	95	290	3.0	250
69	600:1	69000/69000Y	69000	Δ or Y	140	400	3.0	350
92	800:1	92000/92000Y	92000	Δ or Y	185	520	3.0	450
115	1000:1	115000/115000Y	115000	Δ or Y	230	630	3.0	550
138	1200:1	138000/138000Y	138000	Δ or Y	275	750	3.0	650
161	1400:1	161000/161000Y	161000	Δ or Y	325	865	3.0	750
196	1700:1	196000/196000Y	196000	Δ or Y	395	1035	3.0	900
230	2000:1	230000/230000Y	230000	Δ or Y	460	1210	3.0	1050
287	2500:1	287000/287000Y	287000	Δ or Y	575	1500	3.0	1300
345	3000:1	345000/345000Y	345000	Δ or Y	690	1785	3.0	1550
GROUP 3—25 Kv to 345 Kv—Reduced Insulation at Neutral End—Grounded Y Application Only								
25	200/120:1	25000 Grd Y/14400	24000	Grd Y only	50	175	3.0	150
34.5	300/175:1	34500 Grd Y/19900	34500	Grd Y only	70	230	3.0	200
46	400/240:1	46000 Grd Y/26600	46000	Grd Y only	95	290	3.0	250
69	600/350:1	69000 Grd Y/39800	69000	Grd Y only	140	400	3.0	350
92	800/480:1	92000 Grd Y/53100	92000	Grd Y only	185	520	3.0	450
115	1000/600:1	115000 Grd Y/66400	115000	Grd Y only	230	630	3.0	550
138	1200/700:1	138000 Grd Y/79700	138000	Grd Y only	275	750	3.0	650
161	1400/800:1	161000 Grd Y/93000	161000	Grd Y only	325	865	3.0	750
196	1700/1000:1	196000 Grd Y/113000	196000	Grd Y only	395	1035	3.0	900
230	2000/1200:1	230000 Grd Y/133000	230000	Grd Y only	460	1210	3.0	1050
287	2500/1500:1	287000 Grd Y/166000	287000	Grd Y only	575	1500	3.0	1300
345	3000/1800:1	345000 Grd Y/199000	345000	Grd Y only	690	1785	3.0	1550

*A ground stud may be furnished on the neutral end unless otherwise specified.

TABLE 5-G
STANDARD BURDENS FOR STANDARD 5-AMPERE SECONDARY CURRENT TRANSFORMERS

Designation of Burden	Standard Burden Characteristics		Standard Secondary Burden Impedance Ohms and Power Factor and Standard Secondary Volt-ampere Burdens					
			For 60-Cycle and 5-Amp Secondary Current			For 25-Cycle and 5-Amp Secondary Current		
	Resistance Ohms	Inductance Millihenrys	Impedance Ohms	Volt-Amperes*	Power Factor*	Impedance Ohms	Volt-Amperes*	Power Factor*
B-0.1	0.09	0.116	0.1	2.5	0.9	0.0918	2.3	0.98
B-0.2	0.18	0.232	0.2	5.0	0.9	0.1836	4.6	0.98
B-0.5	0.45	0.580	0.5	12.5	0.9	0.4590	11.5	0.98
B-1	0.5	2.3	1.0	25	0.5	0.617	15.4	0.81
B-2	1.0	4.6	2.0	50	0.5	1.234	30.8	0.81
B-4	2.0	9.2	4.0	100	0.5	2.468	61.6	0.81
B-8	4.0	18.4	8.0	200	0.5	4.936	123.2	0.81

* The burden may also be designated by means of the volt-ampere and power factor characteristic: e.g. 50 va at 5 amperes and 0.5 power factor.

the transformer is connected line-to-ground.

The standard ratios result in a nominal secondary voltage of 120 up to a line-to-line voltage of 24 kv inclusive and a nominal secondary voltage of 115 from 34.5 kv through 345 kv.

It will be noted that for all instrument transformers the insulation class voltage ratings are line-to-line voltages of three-phase circuits. For single-phase circuits with one line permanently grounded, the insulation class for transformers would be determined by multiplying the nominal circuit voltage by $\sqrt{3}$. Thus for a 5-kv single-phase line, ungrounded, the insulation class would be 5 kv but if one line is permanently grounded, the insulation class would be 8.7 kv.

In choosing the insulation class rating of instrument transformers therefore, consideration must be given to the normal circuit voltage, line-to-ground as well as line-to-line, on a three-phase basis. Whether or not a three-phase ungrounded circuit may be re-connected to a three-phase grounded neutral circuit at some relatively near future time (for example, from 4,800 volts ungrounded to 4,800/8,320Y volts grounded), should also be given consideration since the future contemplated changes may dictate the choice of transformers in the higher

TABLE 5-H
STANDARD BURDENS FOR POTENTIAL TRANSFORMERS

Designation of Burden	Secondary Volt-Amperes	Burden Power Factor
W	12.5	0.10
X	25	0.70
Y	75	0.85
Z	200	0.85

TABLE 5-I

STANDARD ACCURACY CLASSES AND CORRESPONDING LIMITS OF *TCF* FOR CURRENT TRANSFORMERS FOR METERING SERVICE

Accuracy Class	Limits of Transformer Correction Factor				Limits of Power Factor (Lagging) of Metered Power Load
	100% Rated Current		10% Rated Current		
	Minimum	Maximum	Minimum	Maximum	
1.2	0.988	1.012	0.976	1.024	0.6–1.0
0.6	0.994	1.006	0.988	1.012	0.6–1.0
0.3	0.997	1.003	0.994	1.006	0.6–1.0
0.5	0.995†	1.005†	0.995	1.005	0.6–1.0

† These values also apply to 150 per cent rated current.

insulation class rating for the present service so that they will be adequate for the contemplated service.

Standard Burdens

(a) For current transformers, see Table 5-G.

(b) For potential transformers, see Table 5-H.

Standard Accuracy Classes for Metering Service

The accuracy classification of instrument transformers for metering service is based on the requirement that the transformer correction factor, *TCF*, shall be within specified limits over a specified range of power factor of the metered load.

The accuracy class is designated by the limiting per cent error caused by the transformer in the range of power factor (lagging) from 0.6 to 1.0 followed by the standard burden designation at which the transformer accuracy is determined.

For current transformers each accuracy class designation includes two ratings of primary current, 100% and 10%.

For potential transformers the accuracy classification is on the basis of 120 volts secondary.

It can be shown that for a *current transformer*, the positive and negative limiting values of the phase angle (β) in minutes, for a known ratio correction factor (RCF_I), may be adequately expressed as

$$\beta = 2600\,(RCF_I - TCF_I)$$

where TCF_I is taken as the minimum and maximum transformer correction factor for the specified limits of power factor of the metered load, as given in Table 5-I. For a *potential transformer*, the positive and negative limiting values of the phase angle (γ) in minutes, for a known ratio correction factor (RCF_E), may be adequately expressed as

$$\gamma = 2600\,(TCF_E - RCF_E)$$

TABLE 5-J

STANDARD ACCURACY CLASSES FOR POTENTIAL TRANSFORMERS FOR METERING SERVICE

Accuracy Class	Limits of Transformer Correction Factor	Limits of Power Factor (Lagging) of Metered Power Load
1.2	1.012–0.988	0.6–1.0
0.6	1.006–0.994	0.6–1.0
0.3	1.003–0.997	0.6–1.0

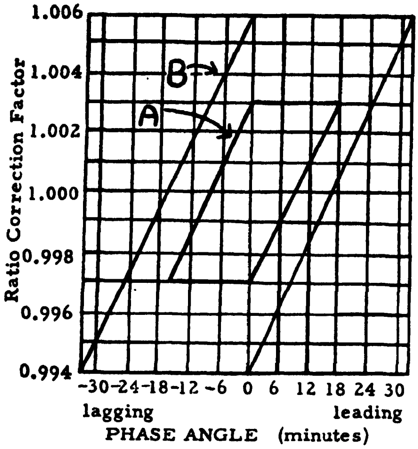


Fig. 5-45a. Limits For Current Transformer Accuracy Class 0.3

The ratio correction factor and phase angle of the current transformer shall be within Parallelogram A at 100% current and within Parallelogram B at 10% current.

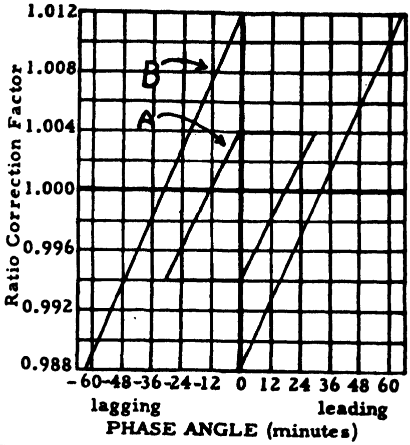


Fig. 5-45b. Limits For Current Transformer Accuracy Class 0.6

The ratio correction factor and phase angle of the current transformer shall be within Parallelogram A at 100% current and within Parallelogram B at 10% current.

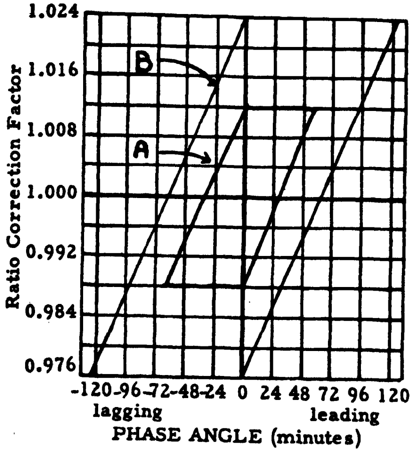


Fig. 5-45c. Limits For Current Transformer Accuracy Class 1.2

The ratio correction factor and phase angle of the current transformer shall be within Parallelogram A at 100% current and within Parallelogram B at 10% current.

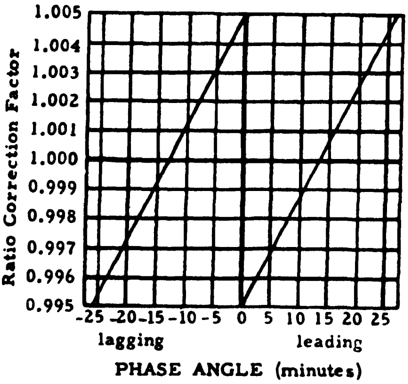


Fig. 5-45d. Limits For Current Transformer Accuracy Class 0.5

The ratio correction factor and phase angle of the current transformer shall be within the Parallelogram from 10% to 150% of rated current.

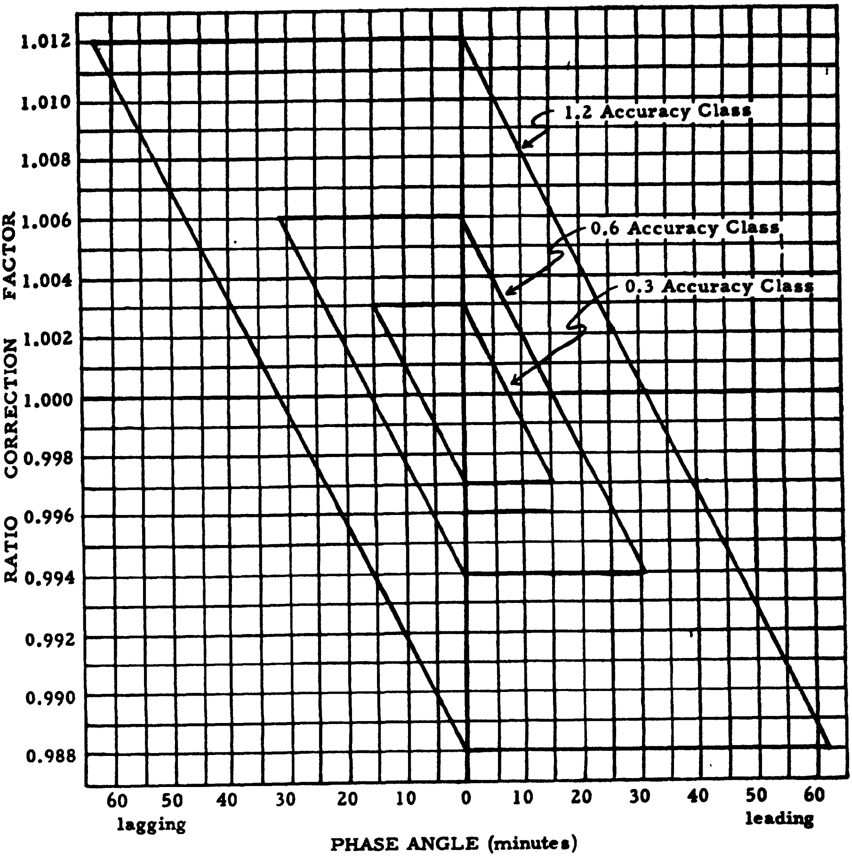


Fig. 5-46. Limits For Potential Transformer Accuracy Classes 0.3, 0.6 and 1.2

The ratio correction factor and phase angle of the potential transformer shall be within the Parallelogram corresponding to the accuracy class. These limits shall apply from 10% below to 10% above rated primary voltage at rated frequency and from zero burden to the rated burden on 120-volt basis.

where TCF_E is taken as the minimum and maximum transformer correction factor for the specified limits of power factor of the metered load as given in Table 5-J.

Since the phase angle does not introduce a significant error when it is small and when the load power factor is 1.0, the limiting values of *RCF* are the same as the limits of *TCF*.

For current transformers, the accuracy classes are given in Table 5-I. The limits may be plotted as shown in Figs. 5-45a, b, c and d.

For potential transformers, the accuracy classes are given in Table 5-J. The limits may be plotted as shown in Fig. 5-46.

The accuracy of a current transformer would then be designated, for example, as 0.3 B-0.5, 0.6 B-2, etc. This means that at burden B-0.5 the transformer would not affect the meter accuracy more than ±0.3% at 100% rated current or ±0.6% at 10% rated current, or at burden B-2 the transformer would not affect the meter accuracy more than ±0.6% at 100% rated current or ±1.2% at 10% rated current, when the power factor of the metered load is between 0.6 and 1.0.

Similarly, the accuracy of a poten-

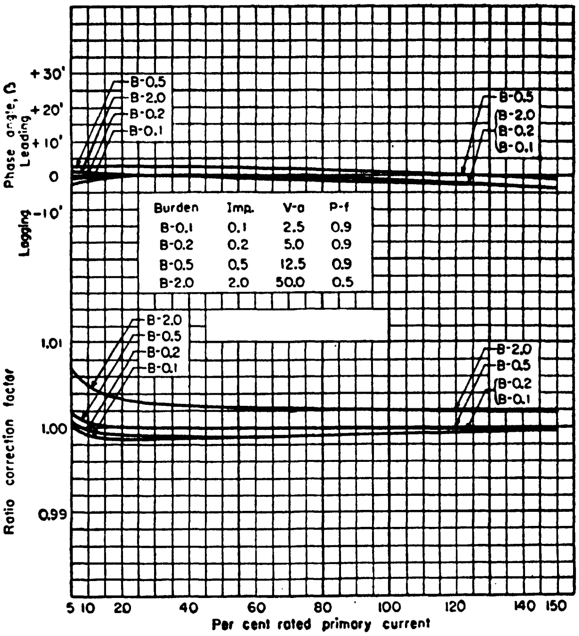


Fig. 5-47. Metering Accuracy Curve of a Current Transformer

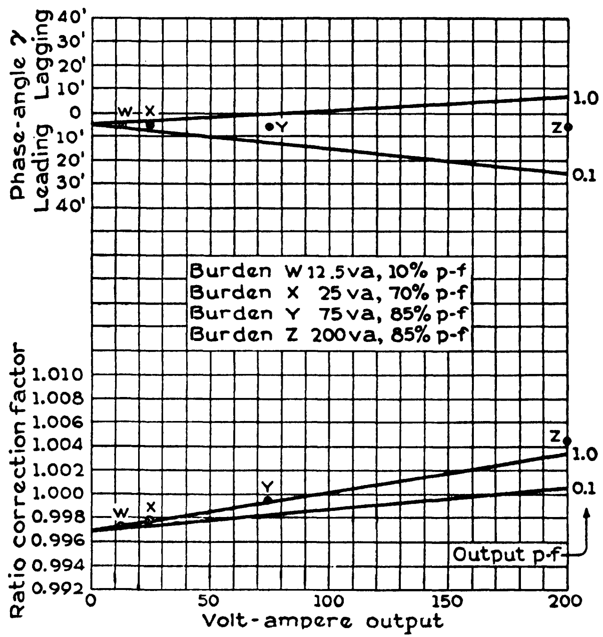
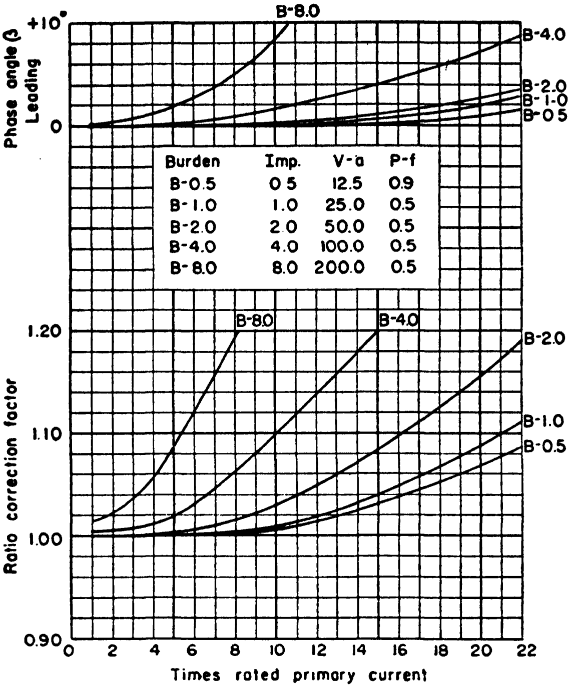


Fig. 5-48. Metering Accuracy Curve of a Potential Transformer



Burden	Imp.	V-a	P-f
B-0.5	0 5	12.5	0.9
B-1.0	1.0	25.0	0.5
B-2.0	2 0	50.0	0.5
B-4.0	4.0	100.0	0.5
B-8.0	8.0	200.0	0.5

Fig. 5-49. Accuracy Curves of a Current Transformer at Heavy Overcurrents

tial transformer would then be designated, for example, as 0.3 X, 1.2 Y, etc. with similar meaning.

Fig. 5-47 shows a metering accuracy curve for a current transformer and Fig. 5-48 shows a metering accuracy curve for a potential transformer.

Standard Accuracy Classes for Current Transformers for Relaying Service

Reference should be made to ASA-C-57 for this information. Fig. 5-49 shows curves of ratio error and phase angle for transformers operating at primary currents greater than covered by the accuracy rating for metering purposes (or for high current overloads).

Standard Impulse Tests

The values of full wave impulse test potential are given in Tables 5-E and 5-F.

Standard Applied Potential Tests

1. The values of normal low frequency test potentials are also given in Tables 5-E and 5-F.
2. The applied potential test for the secondary windings of instrument transformers is 2.5 kv for one minute. (Alternating current rms value.)

EEI-AEIC SPECIFICATIONS FOR COORDINATED AND STANDARDIZED LOW VOLTAGE METERING CURRENT TRANSFORMERS (MS-2—1940)

Purpose

The increased use of low voltage networks and increasing capacities of all low voltage metering makes this development of a coordinated and standardized line of current transformers desirable.

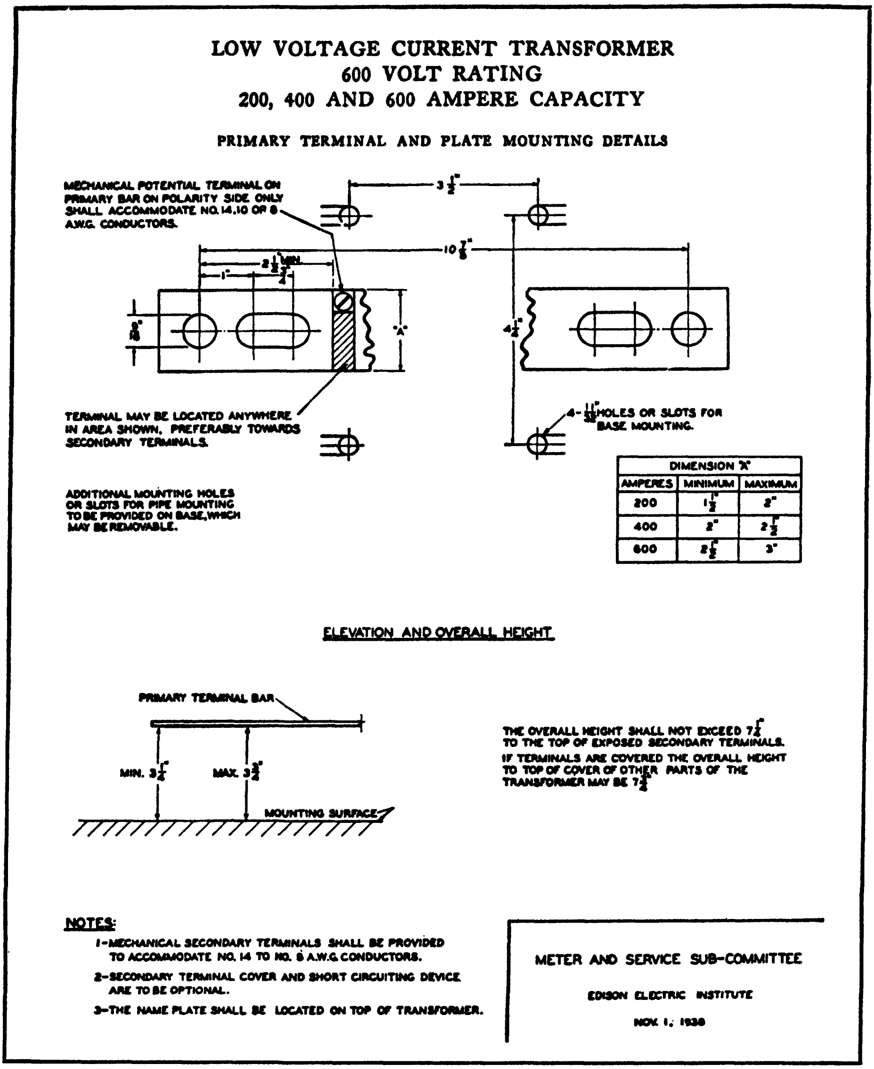

LOW VOLTAGE CURRENT TRANSFORMER
600 VOLT RATING
200, 400 AND 600 AMPERE CAPACITY
PRIMARY TERMINAL AND PLATE MOUNTING DETAILS
MECHANICAL POTENTIAL TERMINAL ON PRIMARY BAR ON POLARITY SIDE ONLY SHALL ACCOMMODATE NO. 14, 10 OR 8 A.W.G. CONDUCTORS.
3 1/2"
10 7/8"
2 1/2" MIN.
1"
3/4"
9/16"
"A"
4 1/4"
TERMINAL MAY BE LOCATED ANYWHERE IN AREA SHOWN, PREFERABLY TOWARDS SECONDARY TERMINALS.
4-11/32" HOLES OR SLOTS FOR BASE MOUNTING.
ADDITIONAL MOUNTING HOLES OR SLOTS FOR PIPE MOUNTING TO BE PROVIDED ON BASE, WHICH MAY BE REMOVABLE.
DIMENSION "A"
AMPERES MINIMUM MAXIMUM
200 1 1/2" 2"
400 2" 2 1/2"
600 2 1/2" 3"
ELEVATION AND OVERALL HEIGHT
PRIMARY TERMINAL BAR
MIN. 3 1/4"
MAX. 3 3/4"
MOUNTING SURFACE
THE OVERALL HEIGHT SHALL NOT EXCEED 7 1/4" TO THE TOP OF EXPOSED SECONDARY TERMINALS.
IF TERMINALS ARE COVERED THE OVERALL HEIGHT TO TOP OF COVER OR OTHER PARTS OF THE TRANSFORMER MAY BE 7 3/4"
NOTES:
1-MECHANICAL SECONDARY TERMINALS SHALL BE PROVIDED TO ACCOMMODATE NO. 14 TO NO. 8 A.W.G. CONDUCTORS.
2-SECONDARY TERMINAL COVER AND SHORT CIRCUITING DEVICE ARE TO BE OPTIONAL.
3-THE NAME PLATE SHALL BE LOCATED ON TOP OF TRANSFORMER.
METER AND SERVICE SUB-COMMITTEE
EDISON ELECTRIC INSTITUTE
NOV. 1, 1938

Fig. 5-50. Primary Terminal and Plate Mounting Details for Low Voltage Current Transformer, 600 Volt Rating, 200, 400 and 600 Ampere Capacity

Requirements

Voltage Rating—600 volts

Current Rating—200/5, 400/5 and 600/5 amperes

Overload Rating—150% of current rating continuously

Temperature Rise—55 C at 150% rated current continuously

Accuracy—ASA accuracy class 0.5 B-0.2

Polarity—standard marking

Terminals and Dimensions — Fig. 5-50 shows primary terminal and plate mounting details, and Fig. 5-51 shows photographs of transformers made in accordance with the specifications.

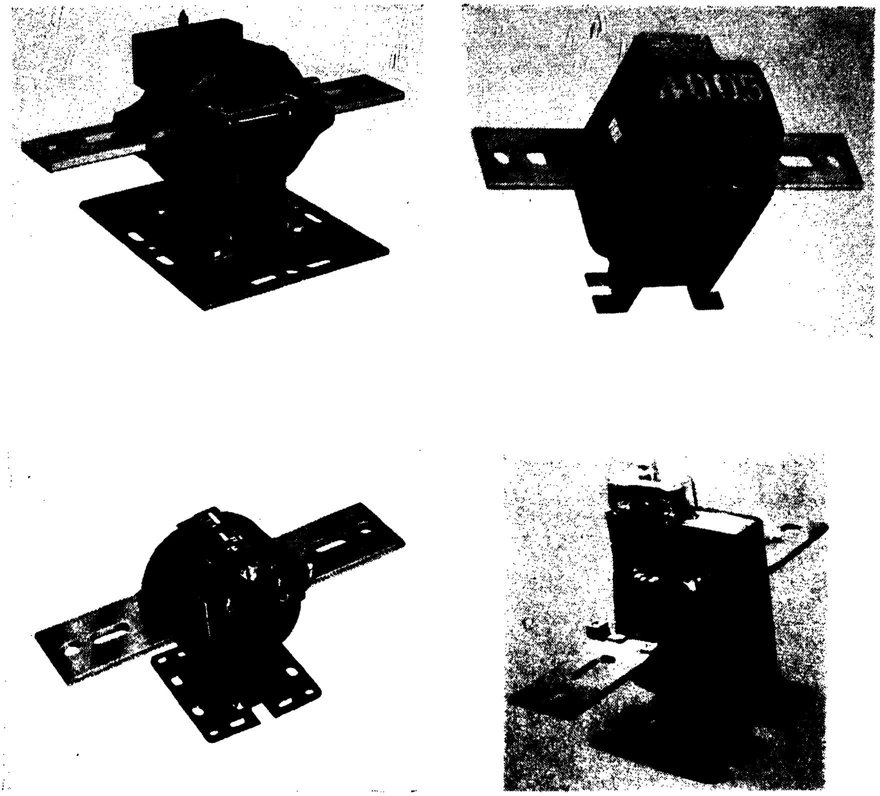


Fig. 5-51. Transformers Made in Accordance with the Specification of MS-2 Available for 600-Volt Service and in Ratings of 200, 400 and 600 Amperes

EEI-AEIC SPECIFICATIONS FOR STANDARD CURRENT TRANSFORMERS FOR PRIMARY CIRCUITS (MS-3—1942)

Purpose

To provide standardized indoor wound-type current transformers in insulation class rating, primary current rating and dimensions.

Insulation Classes and Impulse Levels

Insulation Class (Name Plate Rating)	*Basic Impulse Level*
5.0 kv	60 kv
8.7	75
15 L	95

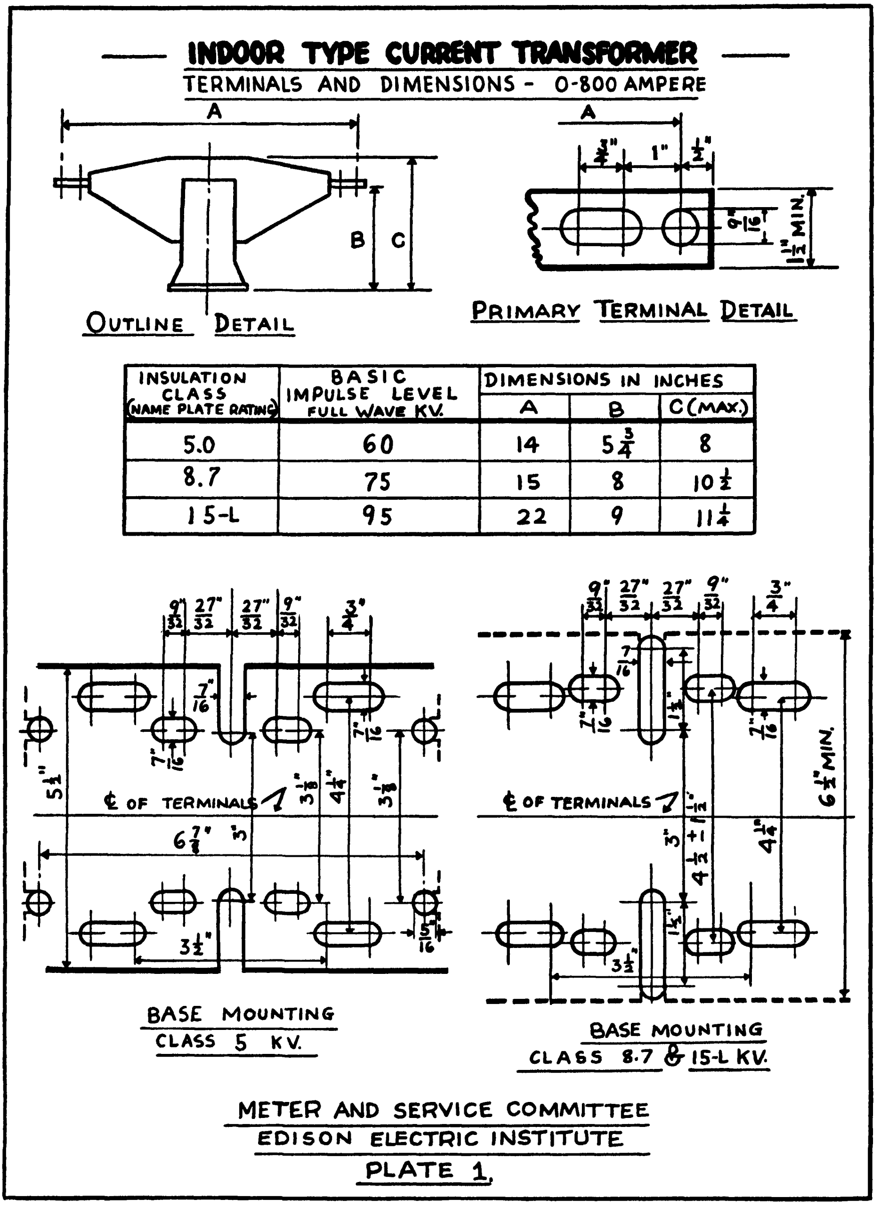
Recommended Ratings for Billing Metering

The recommended ratings are 10, 25, 50, 100, 200, 400, 800 amperes primary to 5 amperes secondary.

It is appreciated that other sizes may be necessary for relaying and other purposes but the above ratings are preferred.

Dimensions

Fig. 5-52 shows terminals and dimensions, and Fig. 5-53 shows photographs of transformers made in accordance with the specifications.



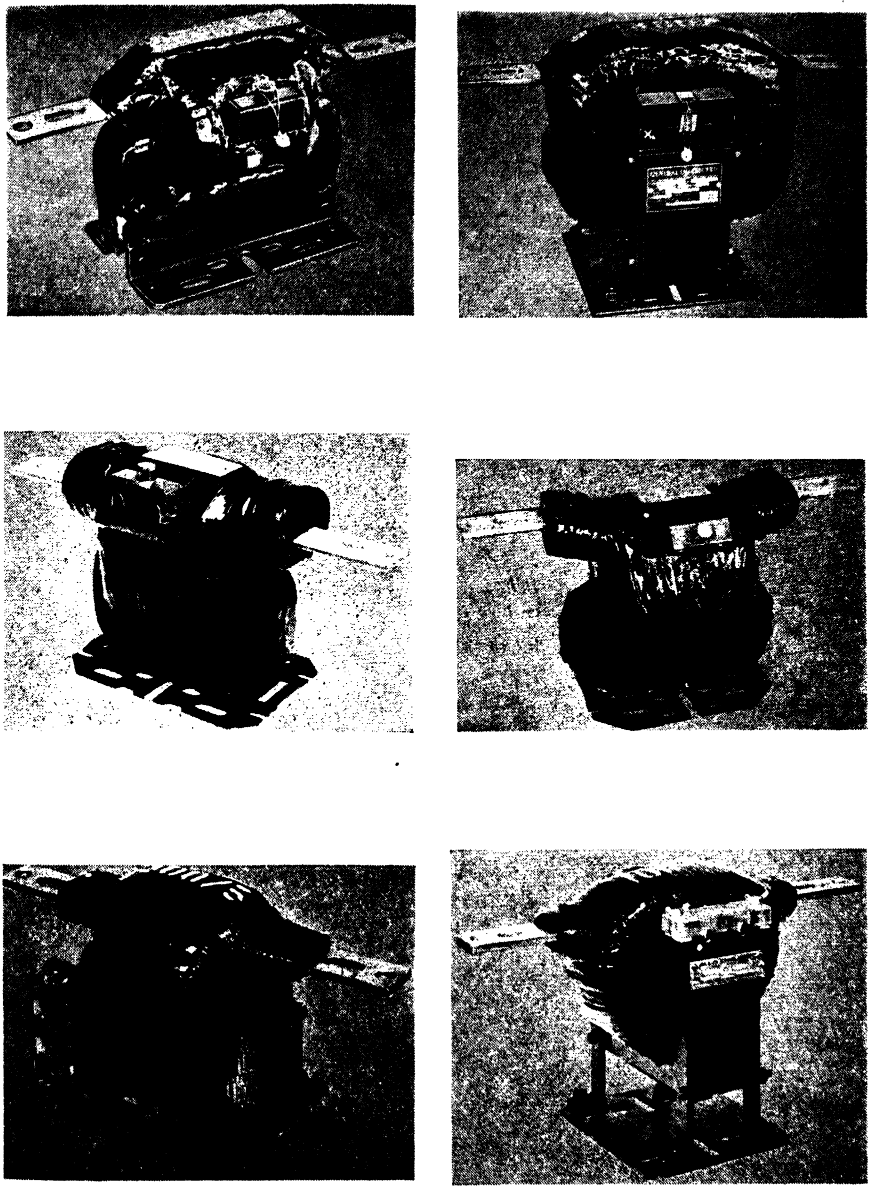
INDOOR TYPE CURRENT TRANSFORMER

TERMINALS AND DIMENSIONS - 0-800 AMPERE

INSULATION CLASS (NAME PLATE RATING)	BASIC IMPULSE LEVEL FULL WAVE KV.	DIMENSIONS IN INCHES		
		A	B	C (MAX.)
5.0	60	14	5 3/4	8
8.7	75	15	8	10 1/2
15-L	95	22	9	11 1/4

METER AND SERVICE COMMITTEE
EDISON ELECTRIC INSTITUTE
PLATE 1.

Fig. 5-52. Standard Dimensions and Terminals of Indoor Type Current Transformers



5-Kv Class

8.7-Kv Class

Fig. 5-53a. Transformers Made in Accordance with the Specifications of MS-3 in 5-Kv and 8.7 Kv Insulation Classes and Ratings from 10 to 800 Amperes

15-Kv Class

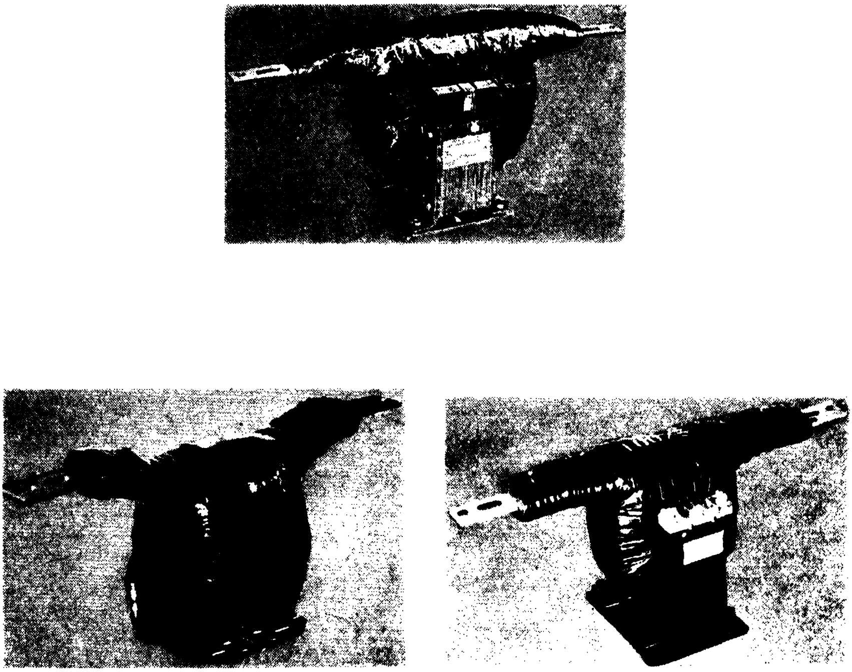


Fig. 5-53b. Transformers Made in Accordance with the Specifications of MS-3 in 15-Kv Insulation Class

SECTION 6

SPECIAL METERING

METERING DOMESTIC WATER HEATER LOADS

Time Switch Control

Domestic water heater loads are usually supplied by utilities at a lower rate than the regular domestic tariff. Separate registration for the water heater load generally is necessary. Because of the lower rate, water heater loads are termed *off peak,* and provision is required for disconnecting these loads during *on peak* periods. A common method consists of a regular watthour meter for the house load, and a separate meter and a time switch for the water heater load. Time switches are operated by synchronous motors, and their contacts open the water heater circuit during the on peak periods determined by the individual utilities for their systems.

Combination watthour meters and time switches have been developed that combine the watthour meter and the time switch in a single case. These combination devices may have either the usual four-dial register, or they may be equipped with a two-rate register, so that off peak and on peak energy are indicated on separate dials. The register and time switch combination replaces the standard watthour register on a meter and, together with a special cover, constitutes the combination watthour meter and time switch. The various types are illustrated in Figs. 14-13, 14-14, 15-22, 15-23, 15-24, 16-32 and 16-33.

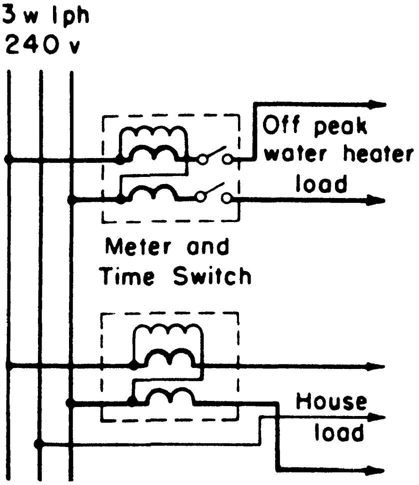


Fig. 6-1. Single-phase Three-wire Meter, with Single-dial Register and Double-pole Contacts for Off Peak Water-heater Load. Separate Metering for House Load

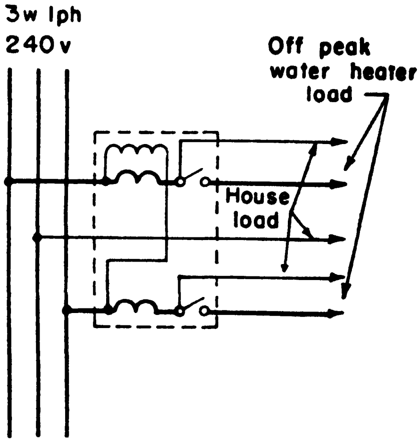


Fig. 6-2. Single-phase Combination Meter and Time Switch with Single-dial Register and Double-pole Contacts for Off Peak Water Heater and House Load

Fig. 6-1 shows the connection of a combination meter and time switch with a single-rate four-dial register and double pole contacts for controlling the off peak water heater load. A separate meter is used for the house load. This combination is applicable where the water heater load is supplied at a different rate from the house load.

Fig. 6-2 shows a combination meter and time switch with a single-rate register and double-pole contacts for controlling the off peak water heater load. The meter registers both the house load and the water heater load, the latter being disconnected during on peak periods. This arrangement is suitable when the regular domestic rate applies also to the water heater load, or where a definite number of kilowatthours during the billing period is assigned to the water heater load by the tariff.

Fig. 6-3 shows a combination meter and time switch with a two-rate register and double-pole contacts for disconnecting the water heater during on peak periods. This connection applies where house load used during off peak periods, together with the water heater load, is billed at the off peak rate.

Fig. 6-4 shows a combination meter and time switch with a two-rate register but without contacts for the water heater load. The water heater remains connected to the service at all times. The time switch serves to control only the set of dials on which the registration is recorded. In this case, the water heater load may be billed at the regular domestic rate, or a specified number of kilowatthours during the billing period may be assigned by the tariff to the water heater load.

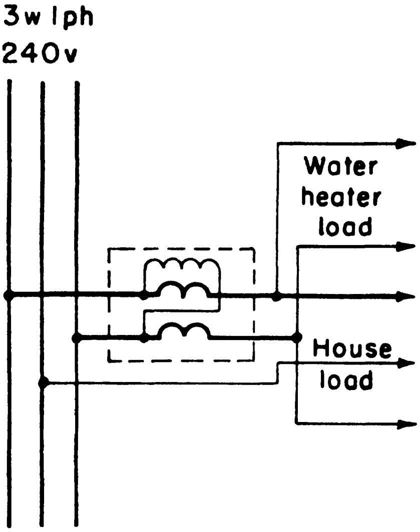


Fig. 6-4. Single-phase Combination Meter with Two-rate Register and Time Switch Without Contacts, for Water Heater and House Load

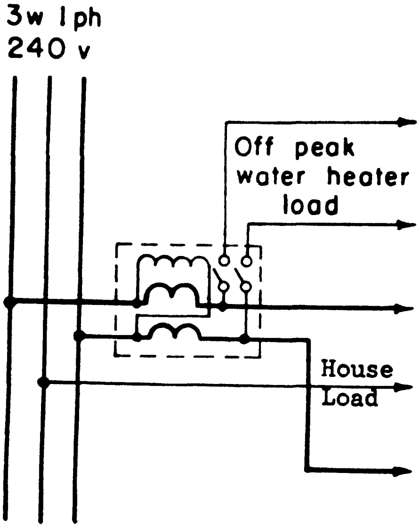


Fig. 6-3. Single-phase Combination Meter and Time Switch with Two-rate Register and Double-pole Contacts for Off Peak Water Heater Load and House Load

The several arrangements provided by two-rate register and time switch combinations may be obtained also by separate meters and time switches. Examples are the solenoid-operated two-rate register, Figs. 15-25, 15-26, and separate time switches, Figs. 15-27 and 16-34.

Another method uses only the regular watthour meter without a time switch. By this method, where the water heater load is supplied at a lower rate than the domestic load, the number of kilowatthours that are assigned to the water heater during the billing period is stipulated in the tariff.

Carrier Current Control

Domestic water heater loads may be controlled by carrier current in place of a time switch on the individual installations. Carrier current control utilizes existing power distribution lines and transformers over which the control energy is conveyed from the substation to operate load controlling relays on the individual customers' installations.

At the substation, a small motor-generator supplies sufficient high-frequency carrier current to energize one feeder at a time. By means of a push button panel equipped with a plug-and-jack arrangement, the operator can connect the output of the high-frequency generator to the series coupling transformer in any desired feeder, thus controlling the water heaters on each feeder independently of those on the other feeders.

The load controller is installed and wired into the water heater circuit in essentially the same manner as a time switch. It consists of a resonant relay circuit connected across the secondary circuit, and is actuated directly by the carrier current transmitted from the substation. This relay operates a toggle-type load contactor which closes the water heater supply when energized for ten seconds, and opens it when energized for thirty seconds.

With this arrangement, there is no practical limit, either to the number of controllers that can be used with one transmitter, or the number of feeders over which selective control can be accomplished from a substation. Also, by employing a two-frequency transmitter, the same substation equipment can be used to control street lighting separately from the water heater load. Typical frequencies used in this work are 480 and 720 cycles.

This system possesses the advantage of permitting the disconnection of water heaters at times of unforeseen peak loads on the system or on parts of the system. Its disadvantages are the relatively higher cost of the equipment, the number of transmitting substations required on a large system with many substations, and the added complications incidental to operation from unattended substations.

References

General Electric Company — *New Equipment for a Method of Controlling Off Peak Loads.* GEA-2245.

Report by the Wiring Committee of the Edison Electric Institute: *P-3 Appliance Installation Manual.* Edison Electric Institute, New York, N. Y.

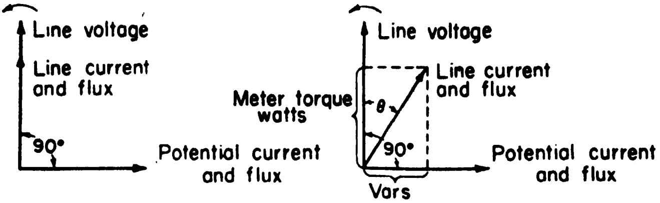
Manufacturers' Bulletins on Watthour Meter Time Switch Combinations.

SINGLE-PHASE VARHOUR AND VOLT-AMPERE-HOUR MEASUREMENTS

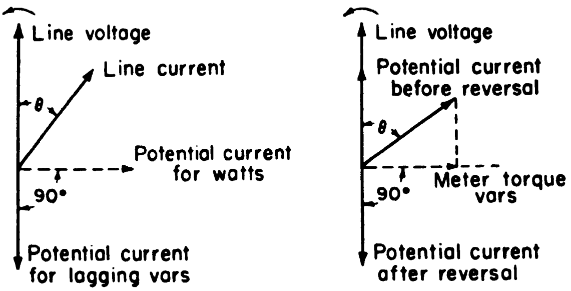
Varhour Measurements

As indicated in Section 3, a watthour meter may be converted into a varhour meter by displacing the potential flux by 90° from that used for a watthour meter. In polyphase circuits this displacement is generally obtained by means of autotransformers. For single-phase circuits a capacitor-resistor unit, calibrated for the particular meter, may be placed in series with the potential circuit so that the potential circuit current is at unity power factor. The meter will then register varhours. Fig. 7-28 shows the connections of a capacitor-resistor unit to a watthour meter on a two-wire circuit. Fig. 6-5 shows vector diagrams of the principle used in single-phase varhour metering.

The characteristic load curve of the varhour meter will be approximately the same as the load curve of a watthour meter. Similarly the voltage curve will practically match the standard voltage curve. The frequency characteristics will be relatively poor, since, with a change in frequency, there will be a change in the ratio of capacitance to resistance in the unit. For the same reason, the overall ambient temperature accuracy will be inferior to that of a watthour meter. The potential circuit watts loss will be increased, since it represents approximately the potential circuit current at unity power factor. The determination of average power factor and kva from watthour and varhour meter readings is described in Section 3.



(a) Watthour meter, 1.0 p-f (b) Watthour meter, p-f θ


Line voltage
Line current
θ
Potential current for watts
90°
Potential current for lagging vars
Line voltage
Potential current before reversal
θ
Meter torque vars
90°
Potential current after reversal

(c) Potential currents in watthour meter and varhour meter

(d) Varhour meter, p-f θ

Fig. 6-5. Vector Diagrams Showing Principle of Single-phase Varhour Metering

Volt-Ampere-Hour Measurements

The connection of a capacitor-resistor unit shown in Fig. 7-28 for a varhour meter applies also to the conversion of a single-phase watthour meter to a volt-ampere-hour meter of limited applicability, and provides sufficient accuracy for commercial purposes, as for example where the desired measurement is the volt-ampere demand. While for the varhour meter a 90° shift in phase for the applied potential is required, the angle of lead required for volt-ampere-hour measurement is 180° minus the desired over-lagged angle. Fig. 6-6 illustrates the vector relations. By reversing the voltage on the potential coil the potential coil current and flux assumes a position lagging the watthour meter potential flux by θ degrees. The maximum meter-torque conditions exist when the line current lags the line voltage by θ degrees, and the meter will integrate the true volt-ampere-hours ($EI \times t$) at power factor cos θ.

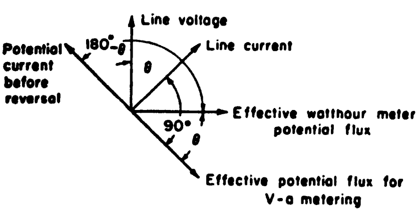

Line voltage
Potential current before reversal
180°-θ
θ
Line current
Effective watthour meter potential flux
90°
θ
Effective potential flux for V-a metering

Fig. 6-6. Vector Relations for Single-phase Volt-ampere-hour Meter

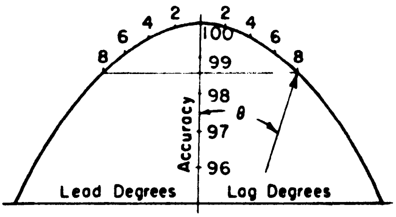


Fig. 6-7. Accuracy of a Watthour Meter when Measuring Volt-ampere-hours Near Power Factor 1.0

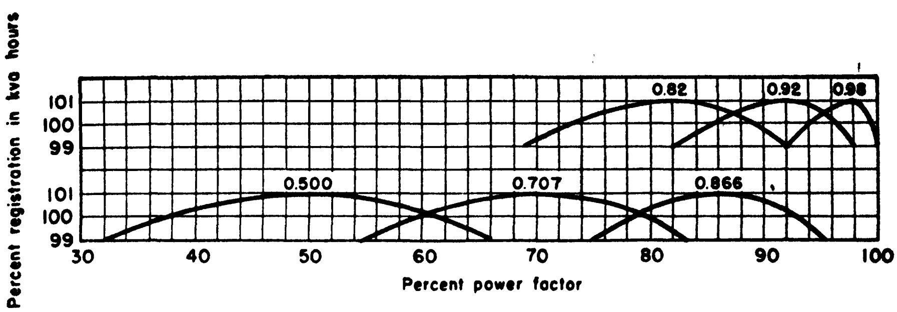


Fig. 6-8. Accuracy of a Volt-ampere-hour Meter Adjusted One Per Cent Fast for Typical Power-factor Ranges

A watthour meter integrates the vector product of *EI* cos θ and from the cosine table, Section 18, it is apparent that the angle θ may go to 8 degrees lead or lag without cos θ departing from unity more than one per cent, Fig. 6-7. Similarly, the cosine table shows that angle θ may go to 11½ degrees lead or lag with a resulting error of not over two per cent. If the watthour meter is adjusted one per cent fast at unity power factor, it would be only one per cent slow when $\theta = +11\frac{1}{2}$ degrees. Thus, if a watthour meter has its potential flux displaced to an average power factor angle, and the meter is then calibrated one per cent fast, it will read volt-ampere-hours over an angular range of plus or minus 11½ degrees from the average angle (total angular range 23 degrees) with a maximum error of one per cent and an average error of zero for any reasonable power factor variation. Fig. 6-8 shows typical accuracy curves.

Volt-Ampere-Hour Meter Test—The calibration of a single-phase volt-ampere-hour meter having a meter test constant $K_h = 0.6$ is assumed. A watthour meter is calibrated accurately at rated current and 10 per cent rated current power factor 1.0, and at full load power factor 0.5. The magnet strength is then reduced in accordance with the average power factor; for example, 20 per cent for an average power factor of 0.80. The capacitor-resistor unit is connected in series with reversed potential coil voltage, Fig. 6-9. The resistance of the capacitor-resistor unit is adjusted so that the volt-ampere-hour meter will run at rated full-load speed of 16 2/3 rpm (3.6 seconds per revolution of the disk) at rated power factor, and at full load timing divided by rated power factor: for example 3.6/0.8 = 4.5 seconds per revolution of the disk at power factor 1.00. Light load and finally full load is checked at power factor 0.5. Timing of the disk per revolution at any

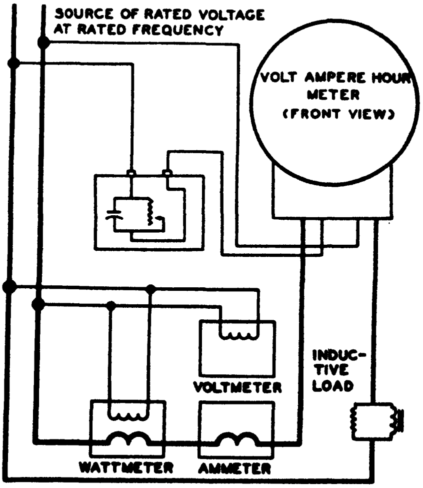

SOURCE OF RATED VOLTAGE AT RATED FREQUENCY
VOLT AMPERE HOUR METER (FRONT VIEW)
INDUCTIVE LOAD
VOLTMETER
WATTMETER
AMMETER

Fig. 6-9. Test Connections for Single-phase Volt-ampere-hour Meter with Capacitor-resistor Unit

power factor and load is given by the formula

$$t = \frac{3600 \times K_h \times R}{W \cos(\theta - \phi)}$$

where K_h = watthour constant
R = revolutions of disk per minute
W = watts as measured by wattmeter
θ = power factor angle of load in degrees
ϕ = rated power factor angle of meter in degrees
t = desired timing of disk per revolution in seconds

An alternative method of phase displacement may be used for angles of less than 20 degrees, since in general with modern meters, it is possible to shift the potential flux to the desired average lag angle by using an oversize meter lag plate. This eliminates the necessity for a capacitor-resistor unit.

COMPENSATING METERING FOR TRANSFORMER LOSSES

In metering loads supplied at transmission or distribution voltages, economies may be effected in many cases by metering on the low-voltage side, and compensating the metering for the power transformer losses. Generally speaking the relative cost of instrument transformers at the supply voltage as compared with the utilization voltage is the best index to the economic advisability of considering these methods. Two methods of application are described, the compensating meter, and the transformer-loss compensator. Both operate on the same fundamental principles.

Principles

The losses in power and distribution transformers consist of iron losses and copper losses.

Iron losses consist principally of those due to magnetic hysteresis and those due to eddy currents. They are constant for constant voltage and frequency. With variations in voltage, iron losses vary approximately as the square of the voltage, and thus may be measured by a metering element whose registration is proportional to E^2.

Copper losses vary as the square of the load current, and increase approximately 20 per cent with an increase in temperature from 25 to 75 C. Since transformers on customers' installations are in continuous service, the losses at 75 C serve as a basis for loss determinations. For any particular transformer the loss data at 75 C may be furnished by the manufacturer.

Metering compensated for transformer losses should be connected to the transformers ahead of disconnecting devices on the low-voltage side so that core losses may be registered even though the load be disconnected. For most types of construction, the metering point is the point where the potential circuits (or the potential transformers) of the meter are connected to the low-voltage circuit.

Conductor losses on the low-voltage side between the transformer and the metering, properly are included in the registration. While these may be negligible in some cases, in establishing a routine it is desirable to include conductor losses so that their inclusion is automatic when these losses assume appreciable proportions. Conductor copper losses are added to the copper losses of the transformers since both vary as the square of the current.

Compensating Meters—The compensating meter consists of an E^2 element and one or more I^2 elements. Fig. 6-10 illustrates the principle of opera-

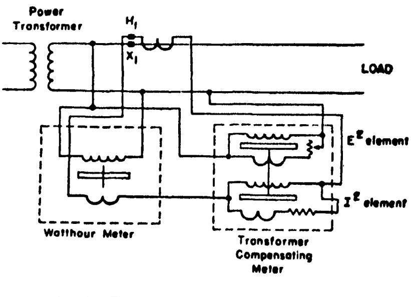


Fig. 6-10. Principle of Compensating Meter

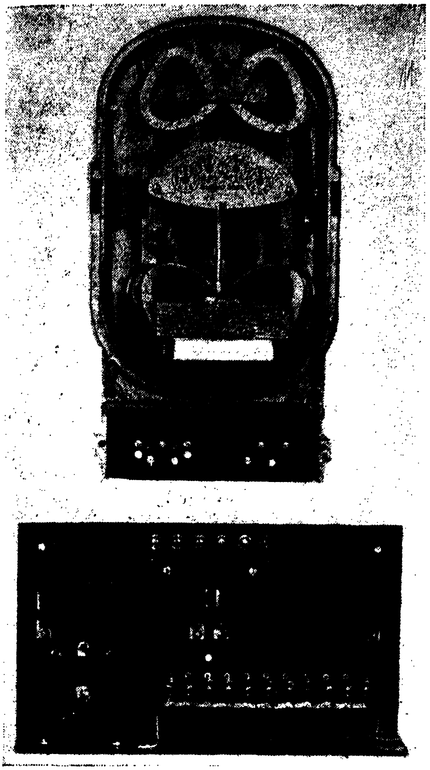


Fig. 6-11. Three-element Compensating Meter (Type V-21) with Resistor Assembly, for Loss Measurements on Three-phase Three-wire Circuits. (General Electric Co.)

tion. For a two-element meter installation, a compensating meter has three elements, Fig. 6-11, and for a three-element meter installation the compensating meter has four elements. An E^2 element consists of a watthour meter element with a standard potential coil and a 0.1 ampere current coil. The latter is connected in series with an adjustable resistor that serves as the core loss adjustment. An I^2 element consists of a watthour meter element with a standard current coil and a low-voltage potential coil connected across a series resistor in the current circuit. Registration therefore is proportional to I^2. Standard compensating meters as supplied have a speed of 3.6 seconds per revolution of the disk with five amperes flowing through the current circuits of all elements. Calibration at heavy load is effected by adjusting the permanent magnets, and at light load by the light-load adjustment associated with the potential coil of the E^2 element. The register ratio may be selected so that the loss registration is in kilowatt-hours, and if a demand register is used, the loss increment of maximum demand will then be in kilowatts. Since the maximum loss demand will be coincident with the maximum load demand, the loss demand may be added to the load demand for billing purposes; or, if desired, the load and loss demands may be combined to record on a single demand meter. Fig. 6-12 shows the connections of a three-phase three-wire meter installation.

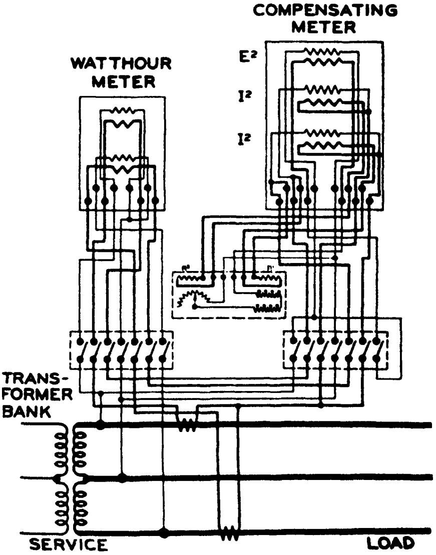


Fig. 6-12. Connections for a Three-phase, Three-wire Compensating Meter Installation

Transformer-Loss Compensators—In compensating for losses with a transformer-loss compensator, a watthour meter, adjusted in the usual manner, is used on the low-voltage side. A transformer-loss compensator is connected into the current and potential circuits and causes the meter to include the loss increment in its registration. The compensator is calibrated for the losses of the installation, and the technique that is described makes possible the calibration of the compensator with the same test equipment that is used for watthour meters.

The transformer-loss compensator consists of a number of small transformers. For iron-loss compensation a 115/230:3-volt transformer has its primary connected to the low-voltage supply, and the 3-volt secondary is connected in series with an adjustable resistor so that a current equivalent to the iron loss is passed through the current coil of the meter. As the iron-loss current so produced is proportional to the voltage, the iron-loss increment as registered by the meter is proportional to the *square* of the voltage.

For including the copper-loss increment, a small current transformer has its primary connected in series with the current coil of the meter and an adjustable resistor connected to its secondary. The connections are such that the drop across the resistor is added to the voltage applied to the meter. As the copper-loss component so produced is proportional to the current, the copper-loss increment as registered by the meter is proportional to the *square* of the current. Compensation for the flow of the potential circuit current through the copper-loss element is provided. Fig. 6-13 shows the principle of operation. Commercial transformer-loss compensators are produced by the Eastern Specialty Company of Philadelphia. Fig. 6-14 shows the connection of a transformer-loss compensator in a two-element meter circuit, and Fig. 6-15 shows an early transformer-loss compensator installation. Three-element compensators, suitable for connection to three-element meters differ only in the addition of the third element.

In applying this method, the losses are determined in per cent of load at the light, heavy and inductive load test points of the meter. The meter remains a standard measuring instrument, and the compensator is calibrated by tests on the meter with and without compensator.

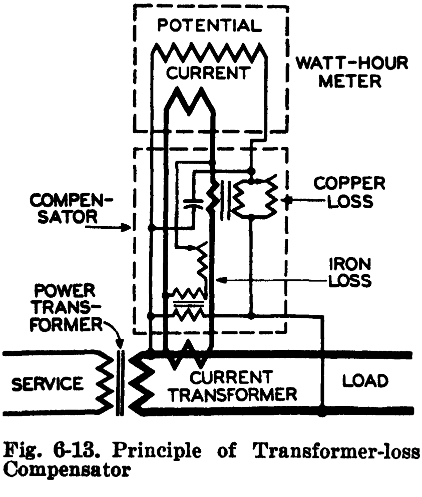


Fig. 6-13. Principle of Transformer-loss Compensator

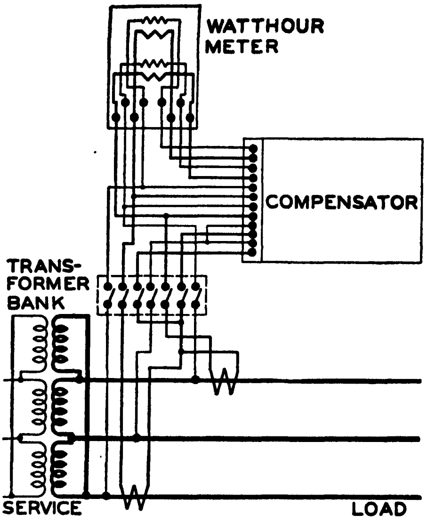


Fig. 6-14. Connections of Meter and Transformer-loss Compensator on a Three-phase, Three-wire Circuit. (Eastern Specialty Co.)

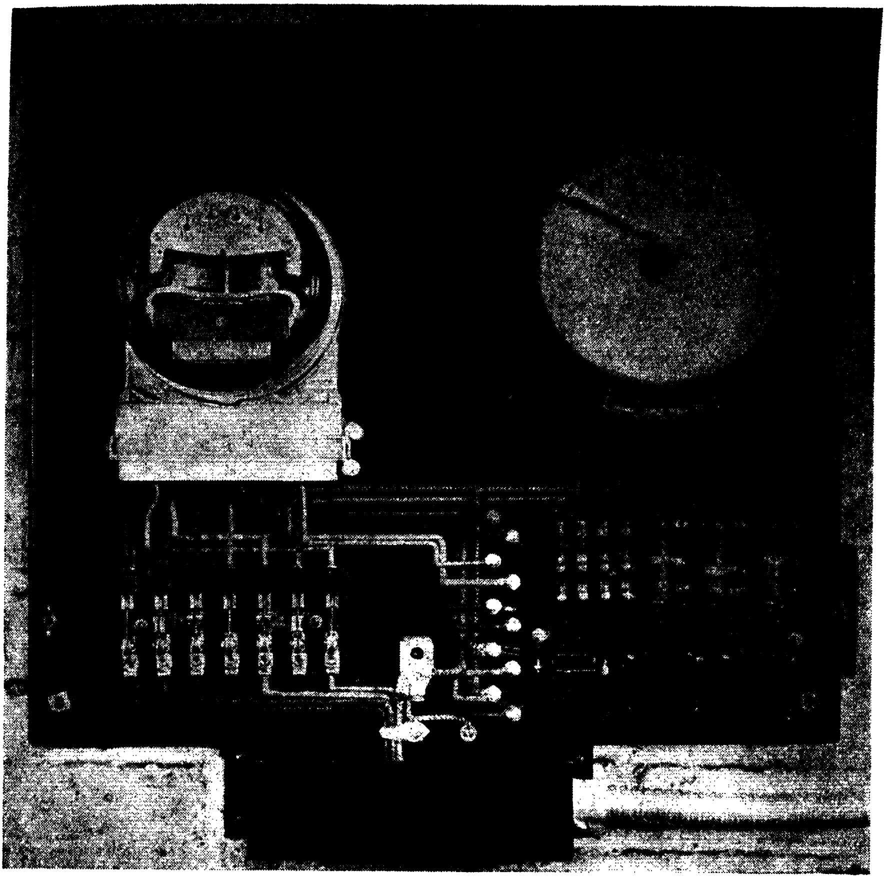


Fig. 6-15. Early Form of Transformer-loss Compensator Installation on a Three-phase, Three-wire Circuit—Panel Cover Removed. (Philadelphia Electric Co.)

Determination of Losses

For both methods of metering, the following information is requested from the manufacturer of the transformers:

Iron loss at rated voltage
Copper loss at 75 C at rated current
The voltage taps provided in the high-voltage and/or low-voltage side

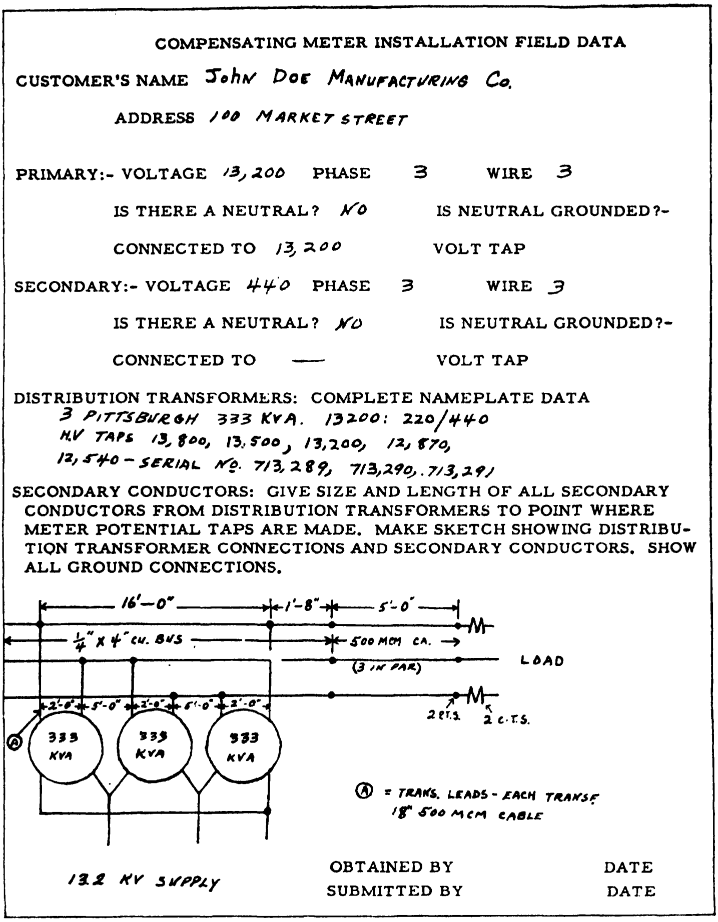
If power-factor tests are intended to be made on the low-voltage side, or if varhour losses also are to be compensated, the following additional information is required:

Per cent exciting current at rated voltage
Per cent impedance

From a field inspection of the installation, data is obtained relative to the taps in use, and the length, size and material of the conductors from the low-voltage side of the transformer bank to the metering point.

Application

In fitting metering methods that provide for loss compensation into



COMPENSATING METER INSTALLATION FIELD DATA

CUSTOMER'S NAME John Doe Manufacturing Co.

ADDRESS 100 MARKET STREET

PRIMARY:- VOLTAGE 13,200 PHASE 3 WIRE 3

IS THERE A NEUTRAL? NO IS NEUTRAL GROUNDED?-

CONNECTED TO 13,200 VOLT TAP

SECONDARY:- VOLTAGE 440 PHASE 3 WIRE 3

IS THERE A NEUTRAL? NO IS NEUTRAL GROUNDED?-

CONNECTED TO —— VOLT TAP

DISTRIBUTION TRANSFORMERS: COMPLETE NAMEPLATE DATA
3 PITTSBURGH 333 KVA. 13200: 220/440
H.V TAPS 13,800, 13,500, 13,200, 12,870,
12,540 – SERIAL No. 713,289, 713,290, 713,291

SECONDARY CONDUCTORS: GIVE SIZE AND LENGTH OF ALL SECONDARY CONDUCTORS FROM DISTRIBUTION TRANSFORMERS TO POINT WHERE METER POTENTIAL TAPS ARE MADE. MAKE SKETCH SHOWING DISTRIBUTION TRANSFORMER CONNECTIONS AND SECONDARY CONDUCTORS. SHOW ALL GROUND CONNECTIONS.

OBTAINED BY DATE
SUBMITTED BY DATE

Fig. 6-16. Field Data Form with Data of a Typical Installation

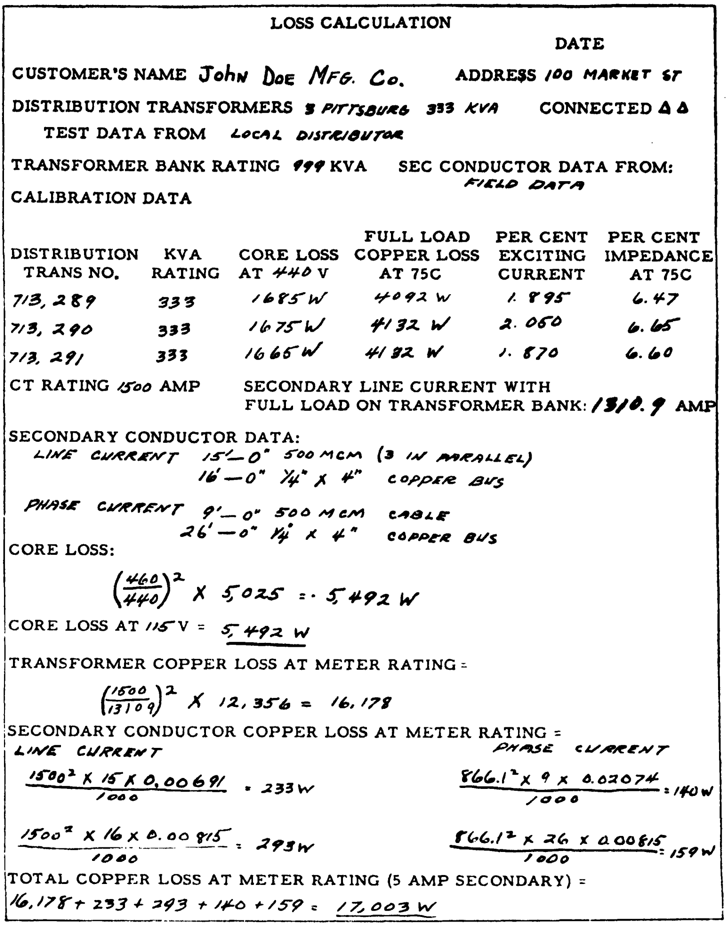
established routines, several forms are useful for collecting the necessary data, and for the loss calculations so that they may be done by metermen with only general engineering supervision. The application of both methods of metering to a specific installation will clarify the procedure.

Conditions Assumed — A 1000-kva transformer bank, consisting of three 13,200/440-volt 333-kva transformers, is connected delta-delta. Metering at 440 volts will be by a two-element instrument-transformer-rated watthour meter connected to two 1500/5-ampere current transformers and two 480/120-volt potential transformers. It is desired to compensate the metering to read as of the 13,200-volt side of the power transformers, using (1) a compensating meter, and (2) a transformer-loss compensator.

A field inspection indicates that the connections from the low-voltage side of the transformers to the metering point consist of the following conductors:

Carrying phase current, each phase: 3 feet 500,000 circular mil copper conductor, and 8 2/3 feet 1/4 by 4 inch copper bus.

Carrying line current, each line:



LOSS CALCULATION

DATE

CUSTOMER'S NAME John Doe Mfg. Co. ADDRESS 100 MARKET ST

DISTRIBUTION TRANSFORMERS 3 PITTSBURG 333 KVA CONNECTED Δ Δ

TEST DATA FROM LOCAL DISTRIBUTOR

TRANSFORMER BANK RATING 999 KVA SEC CONDUCTOR DATA FROM: FIELD DATA

CALIBRATION DATA

DISTRIBUTION TRANS NO.	KVA RATING	CORE LOSS AT 440 V	FULL LOAD COPPER LOSS AT 75C	PER CENT EXCITING CURRENT	PER CENT IMPEDANCE AT 75C
713, 289	333	1685 W	4092 W	1.895	6.47
713, 290	333	1675 W	4132 W	2.060	6.65
713, 291	333	1665 W	4132 W	1.870	6.60

CT RATING 1500 AMP SECONDARY LINE CURRENT WITH FULL LOAD ON TRANSFORMER BANK: 1310.9 AMP

SECONDARY CONDUCTOR DATA:

LINE CURRENT 15′—0″ 500 MCM (3 IN PARALLEL)
16′—0″ 1/4″ X 4″ COPPER BUS

PHASE CURRENT 9′—0″ 500 MCM CABLE
26′—0″ 1/4″ X 4″ COPPER BUS

CORE LOSS:

$$\left(\frac{460}{440}\right)^2 \times 5{,}025 = 5{,}492\ W$$

CORE LOSS AT 115 V = $\underline{5{,}492\ W}$

TRANSFORMER COPPER LOSS AT METER RATING =

$$\left(\frac{1500}{13109}\right)^2 \times 12{,}356 = 16{,}178$$

SECONDARY CONDUCTOR COPPER LOSS AT METER RATING =

LINE CURRENT

$$\frac{1500^2 \times 15 \times 0.00691}{1000} = 233\ W$$

$$\frac{1500^2 \times 16 \times 0.00815}{1000} = 293\ W$$

PHASE CURRENT

$$\frac{866.1^2 \times 9 \times 0.02074}{1000} = 140\ W$$

$$\frac{866.1^2 \times 26 \times 0.00815}{1000} = 159\ W$$

TOTAL COPPER LOSS AT METER RATING (5 AMP SECONDARY) =

$16{,}178 + 233 + 293 + 140 + 159 = \underline{17{,}003\ W}$

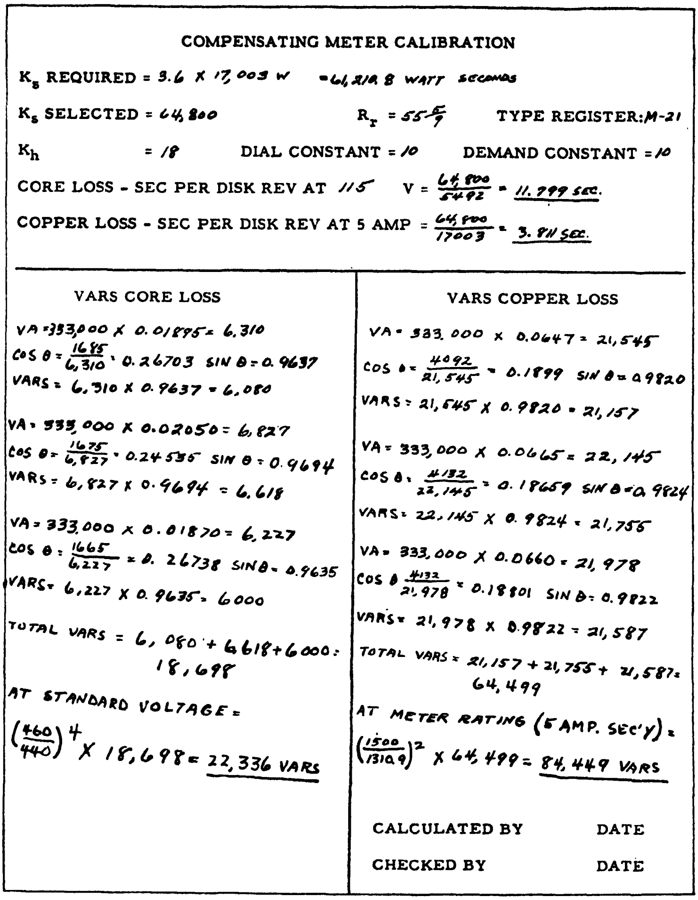
Fig. 6-17. Loss Calculation Form with Data of a Typical Installation

5 feet 500,000 circular mil copper conductor (three in parallel) and 5 1/3 feet 1/4 by 4 inch copper bus.

Standard meter testing practice provides for routine testing of polyphase watthour meters with elements in series on the final test. Tests are made on meters at light load, heavy load and inductive load, for which normal current values are 0.5 and 5.0 amperes at power factor 1.0, and 5.0 amperes at power factor 0.50 lagging. The nominal voltage on the low-voltage side is 460 volts.

Fig. 6-16 shows a field data form on which the data obtained in the field has been entered. This data serves as a basis for requesting loss data from the manufacturer, and for the loss calculations.

Fig. 6-17 shows the form for making the loss calculations. The loss data received from the manufacturer, and the secondary conductor data obtained from the field data form have been entered and the iron and copper losses have been calculated. *Total iron loss* and *total copper loss* results are underlined and these values are used for the additional calculations on the reverse side of the form. Thus far the procedure is identical for both compensating meters and transformer-loss compensators.



COMPENSATING METER CALIBRATION

K_s REQUIRED = 3.6 X 17,003 W = 61,210.8 WATT SECONDS

K_s SELECTED = 64,800 R_r = $55\frac{5}{9}$ TYPE REGISTER: M-21

K_h = 18 DIAL CONSTANT = 10 DEMAND CONSTANT = 10

CORE LOSS - SEC PER DISK REV AT 115 V = $\frac{64,800}{5492}$ = 11.799 SEC.

COPPER LOSS - SEC PER DISK REV AT 5 AMP = $\frac{64,800}{17003}$ = 3.811 SEC.

VARS CORE LOSS

VA = 333,000 X 0.01895 = 6,310
COS θ = $\frac{1685}{6,310}$ = 0.26703 SIN θ = 0.9637
VARS = 6,310 X 0.9637 = 6,080

VA = 333,000 X 0.02050 = 6,827
COS θ = $\frac{1675}{6,827}$ = 0.24535 SIN θ = 0.9694
VARS = 6,827 X 0.9694 = 6,618

VA = 333,000 X 0.01870 = 6,227
COS θ = $\frac{1665}{6,227}$ = 0.26738 SIN θ = 0.9635
VARS = 6,227 X 0.9635 = 6000

TOTAL VARS = 6,080 + 6618 + 6000 = 18,698

AT STANDARD VOLTAGE =
$\left(\frac{460}{440}\right)^4$ X 18,698 = 22,336 VARS

VARS COPPER LOSS

VA = 333,000 X 0.0647 = 21,545
COS θ = $\frac{4092}{21,545}$ = 0.1899 SIN θ = 0.9820
VARS = 21,545 X 0.9820 = 21,157

VA = 333,000 X 0.0665 = 22,145
COS θ = $\frac{4132}{22,145}$ = 0.18659 SIN θ = 0.9824
VARS = 22,145 X 0.9824 = 21,755

VA = 333,000 X 0.0660 = 21,978
COS θ $\frac{4132}{21,978}$ = 0.18801 SIN θ = 0.9822
VARS = 21,978 X 0.9822 = 21,587

TOTAL VARS = 21,157 + 21,755 + 21,587 = 64,499

AT METER RATING (5 AMP. SEC'Y) =
$\left(\frac{1500}{1310.9}\right)^2$ X 64,499 = 84,449 VARS

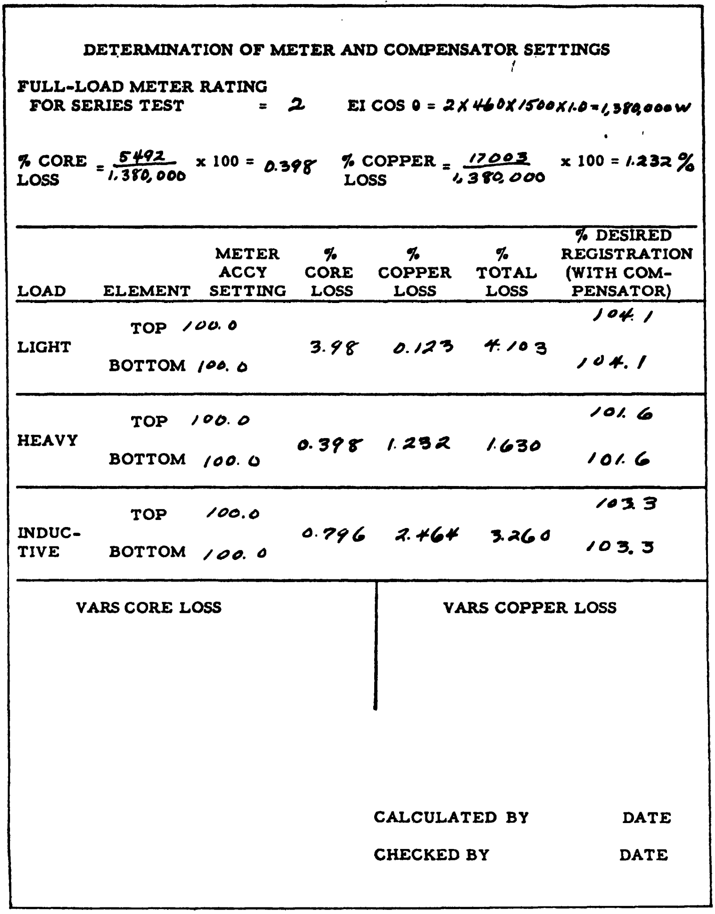
CALCULATED BY DATE

CHECKED BY DATE

Fig. 6-18. Calculation of Calibration for a Compensating Meter (Reverse Side of Form in Fig. 6-17)

Compensating Metering—Fig. 6-18 is used for compensating metering, and may be the reverse side of the form shown in Fig. 6-17. The first five lines show the calculation of the calibration for a compensating meter for the installation. This is given in seconds per revolution at 115 volts for the iron-loss element, and at 5 amperes for the copper-loss element. The calculations for var loss on the lower part of the form are needed only if power factor determinations are made on the low-voltage side, either by test or continuous measurement. For the latter, the vars iron loss and the vars associated with copper loss serve for determining the calibration of a compensating varhour meter in the same way as described for a watthour meter.

Transformer-Loss Compensator—For use with a transformer-loss compensator the reverse side of the form shown in Fig. 6-17 is shown in Fig. 6-19. The losses at the light-load, heavy-load and inductive-load test points are calculated in terms of the kw loads at which the meter is tested. For a polyphase meter at the heavy load test point this is the product of the number of elements of the meter



DETERMINATION OF METER AND COMPENSATOR SETTINGS

FULL-LOAD METER RATING FOR SERIES TEST = 2 EI COS θ = 2 X 460 X 1500 X 1.0 = 1,380,000 W

% CORE LOSS = $\frac{5492}{1,380,000}$ x 100 = 0.398 % COPPER LOSS = $\frac{17003}{1,380,000}$ x 100 = 1.232 %

LOAD	ELEMENT	METER ACCY SETTING	% CORE LOSS	% COPPER LOSS	% TOTAL LOSS	% DESIRED REGISTRATION (WITH COMPENSATOR)
LIGHT	TOP	100.0	3.98	0.123	4.103	104.1
	BOTTOM	100.0				104.1
HEAVY	TOP	100.0	0.398	1.232	1.630	101.6
	BOTTOM	100.0				101.6
INDUCTIVE	TOP	100.0	0.796	2.464	3.260	103.3
	BOTTOM	100.0				103.3

VARS CORE LOSS

VARS COPPER LOSS

CALCULATED BY DATE

CHECKED BY DATE

Fig. 6-19. Calculation of Calibration for a Transformer-loss Compensator (Reverse Side of Form in Fig. 6-17). Computations for vars core loss and vars copper loss—see Fig. 6-18

and the kva rating of each element. The per cent losses for other loads may be calculated by proportion. While copper losses vary as the square of the load current, *per cent* copper loss varies *directly* with per cent load on the meter. Similarly *per cent* iron loss varies *inversely* with per cent load on the meter. Therefore it is simple to determine the per cent loss for any load. For meter test loads at power factors other than 1.0 it is necessary only to divide the per cent iron and per cent copper losses at power factor 1.0 by the desired power factor. Thus the calculations for percentage losses need be made only for the heavy load test point. For the other loads they are determined by proportion as shown in the upper part of Fig. 6-19.

As in the case of compensating meter installations the calculations of var losses are needed only if power factor determinations on the low-voltage side are to be compensated to the supply side, or if a varhour meter is to be used. While Figs. 6-16, 6-17, 6-18 and 6-19 show the calculations for a typical three-phase installation, additional factors apply to transformers with taps and for some transformer connections.

Transformers with Taps—Transformers used on customers' services frequently are provided with taps to permit adjustments in the utilization voltage. Loss data supplied by manufacturers generally is based on the rated voltage, but sometimes on the full winding. Iron losses in watts measured at rated voltage are the same as when connection is made to a tap and its rated voltage is applied. For copper losses of transformers for the service under consideration it is sufficiently close to consider that the losses are divided equally between the high-voltage and the low-voltage windings, and the size of conductors is the same throughout each of the windings. Taps on the high-voltage side are most common. With metering on the low-voltage side, if copper loss is given for rated voltage V_r and voltage tap V_t is used, the multiplier to be applied to copper loss at rated voltage,

$$M_t = V_r/2V_t + 0.5$$

For taps on the low-voltage side with metering also on the low-voltage side,

$$M_t = V_t/2V_r + (1/2)\ (V_t/V_r)^2$$

Multipliers calculated as above for the most common taps are shown in Table 6-A. The multipliers, where required, are incorporated in the formula for *copper loss at meter rating* in Fig. 6-17. Where taps are provided in both windings both multipliers are used.

TABLE 6-A

COPPER-LOSS MULTIPLIERS FOR COMMON TRANSFORMER TAPS WITH LOW-VOLTAGE METERING

Per Cent Tap	Tap on High-Voltage Winding	Tap on Low-Voltage Winding
86.6	1.077	0.808
90.0	1.056	0.855
92.5	1.041	0.890
95.0	1.026	0.926
97.5	1.013	0.963
100.0*	1.000*	1.000*
102.5	0.988	1.038
105.0	0.976	1.076
107.5	0.965	1.115
110.0	0.955	1.155

* Tap on which copper loss data are based.

Transformer Connections—For *open-delta connections*, Fig. 6-12, full-load losses occur when the bank is supplying 86.6 per cent of the sum of the kva ratings of the two transformers. Hence if an open-delta bank were used to supply the installation calculated in Fig. 6-17, the value of line current given would be multiplied by 0.866.

In *Scott connections*, used for two-phase to three-phase transformation, the teaser transformer is connected to the 86.6 per cent tap. In line with Table 6-A therefore, the copper-loss multiplier for the teaser transformer is 1.077 or 0.808, depending on whether the metering is on the two-phase, or on the three-phase side. For the main transformer the copper loss multiplier is 0.875 for metering on the three-phase side, and 1.167 for metering on the two-phase side.

The *three-phase four-wire-delta connection* with a two-element meter involves a special feature. With transformer-loss compensators, where final tests of the meter are made with elements in series, the per cent loss to which the compensator is adjusted applies to the element connected to the single-primary current transformer. The element connected to the double-primary current transformer measures the resultant of two currents displaced by 120°. For this element the percentage copper loss calculated at the top of Fig. 6-19 is multiplied by 1.155. For operation in service the loss increment then will be divided equally between the two elements. Similarly with a compensating meter the speed of the element connected to the double-primary transformer should be increased by the relation

$$1 - 5^2/4.33^2 = 0.333 \text{ or } 33.3\%$$

Meter Tests

Compensating meters may be calibrated and tested with an ammeter and a voltmeter to the required seconds per revolution as determined from the calculations in Fig. 6-18. Where the number of meters warrants, a portable standard compensating meter may be used. This consists of an E^2 element and an I^2 element which are operated separately. The E^2 element operates at 3.6 seconds per revolution for 115 or 230 volts, and the I^2 element operates at 3.6 seconds per revolution for 5 amperes. Service meters therefore may be tested by using the ratio of meter to standard revolutions, in which case variations in current or voltage during the test are automatically compensated for.

For the current (I^2) elements, the full-load adjustment is made by means of the permanent magnets, the potential coil of the E^2 element being energized. For light-load tests use is made of the light-load adjustment of the E^2 element. These tests are conveniently made at 1.5 amperes which gives 9% speed. The E^2 element is calibrated by means of the adjustable resistor in series with the current circuit of the E^2 element.

For transformer-loss compensators the watthour meter and the compensator are connected for test. The watthour meter is adjusted in the usual way by placing the compensator test switch in the *test* position. This disconnects the compensating transformers. When all tests on the meter are completed, the compensator test switch is opened, which places the copper-loss elements in circuit. The copper-loss resistors of the compensator are adjusted at the heavy load test point so that the copper loss is added equally on all elements. (For three-phase four-wire delta meters see *transformer connections*.) Then the compensator test switch is closed in the *normal* position which includes the iron-loss element in the circuit, and test connections are made for the series test. The iron-loss element is adjusted to the calculated light-load setting point. A final check should be made with compensator at all loads. In making inductive load tests, it must be remembered that any deviation in power factor from the nominal value of 0.5 lagging will result in differences from the desired performance. For inductive load tests therefore, it is important that the test results be compared with desired values for the power factor at which the test is made.

TABLE 6-B

INTERPRETATION OF SERVICE TEST RESULTS ON TRANSFORMER-LOSS COMPENSATOR INSTALLATIONS

Per Cent Registration			Conclusion	
With Compensator	Without Compensator	Difference	Whr Meter	Compensator
100.0	100.0	0	Perfect	Perfect
99.8	99.7	+0.1	Satisfactory	Satisfactory
100.3	100.3	0	Satisfactory	Perfect
99.6	99.7	−0.1	Adjust	Satisfactory
99.6	99.6	0	Adjust	Perfect
99.8	100.2	−0.4	Satisfactory	Adjust
100.0	100.4	−0.4	Adjust	Adjust

Tests in service follow the same principles. The *as found* accuracies with compensator *related to the percentages that the meter should read* are the accuracies of the combination. A test on the meter with and without compensator determines the need for adjustment either of the meter or of the compensator. The compensator performance is indicated by the difference between the results of tests with and without compensator. Table 6-B shows the interpretation of typical test results. It is assumed that the permissible test limits are ±0.3 per cent.

If the compensator requires adjustment, errors on the heavy-load test are corrected with the copper-loss adjustments, those at light load with the iron-loss adjustment. If inductive-load tests are desired in the field it is important to establish and correct for the true power factor of the test load. The phase angle of loading devices, and possible variations in the three-phase line voltages all have an effect on the true power factor of the test load.

Any method of meter testing may be used with transformer-loss compensators, but as the total loss curves are not straight lines, the tests with and without compensator should be made at approximately the same test load, and as closely as practicable to the nominal values of test load. Where fixed phantom load devices are used, it is desirable to provide a separate tap in the heavy-load circuit so that approximately the same current will be passed through the meter when the compensator is in the circuit as when it is short circuited for tests on the meter alone.

Other Methods

There are other methods of compensating meters for transformer losses. They are of interest for some circuit arrangements and where the accuracy considerations permit their use.

A meter connected to current transformers on the low-voltage side and to potential transformers on the high-voltage side of a power transformer bank measures the secondary load plus the copper losses. It omits the iron loss. With this connection compensation for iron loss only may be applied to the meter for accurate registration as of the high-voltage side.

Conversely a meter connected to current transformers on the high-voltage side and to potential transformers on the low-voltage side measures the secondary load plus the iron loss. It omits the copper losses. With this connection compensation for copper loss only may be applied to the meter for accurate registration as of the high-voltage side.

Another method uses a meter connected to the low-voltage side and approximates the losses by means of the meter adjustments. As the torque produced by the light-load adjustment of watthour meters is proportional to E^2, it serves as an effective means for adding the core loss registration to the meter. The calculations are the same as for transformer-loss compensators, as shown in Fig. 6-17 and the upper part of Fig. 6-19. The test procedure is the same as for an ordinary watthour meter, the meter being adjusted at light load, heavy load and inductive load to the calculated desired performance. The range of adjustment of watthour meters is sufficient for the conditions under which the method would be used. As the full-load adjustment of the meter is used for adding the copper-loss increment, the copper-loss registration will tend to be high at points below full load. This error may be reduced throughout the load range by setting the full- and inductive-load adjustments slightly lower than the calculated values. This method is limited to conditions where the copper losses are low, or for statistical metering where extreme accuracy is not required.

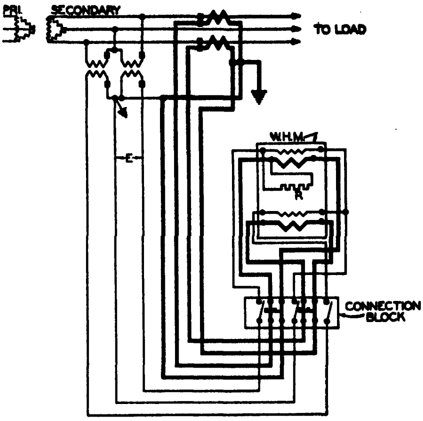


Fig. 6-20. Connections of Watthour Meter with Resistor Compensation for Core Loss

A sixth method uses a regular watthour meter and a resistor for adding the losses to the meter registration on the low-voltage side. Since the total core and copper losses of a modern transformer bank may be only 0.5 to 1.0 per cent of the full-load rating of the bank, this method of metering introduces errors which are only a fraction of the tolerances encountered in adjusting a watthour meter in normal service. A regular watthour meter is used to measure the core and copper losses of the customer's transformer bank and the load.

A three-wire three-phase application is shown in Fig. 6-20, although the method is not restricted to this type of service. The watthour meter is connected to the secondary side of the transformer bank in the usual manner. A resistor *R* is connected to the meter circuit in such a manner that it is energized by the meter voltage E. The watt loss of this resistor is measured by one element of the watthour meter. The watt loss of the resistor is equal to E^2/R, and since R may be fixed at a constant value the watt loss will vary as E^2. Thus it may be used for the measurement of the core losses of the transformer bank.

The measurement of copper losses is accomplished by adjusting the watthour meter at full load and at light load so that its performance curve follows the copper-loss curve of the transformer bank. For any specified value of copper losses, the meter adjustment required to measure the copper losses is proportional to the load; for example, the adjustment of 10% meter load is 1/8 of that for 80% meter load. Therefore by proper adjustment of the watthour meter at light and heavy load, the meter will record an additional amount of energy approximately equal to the copper losses of the transformer bank.

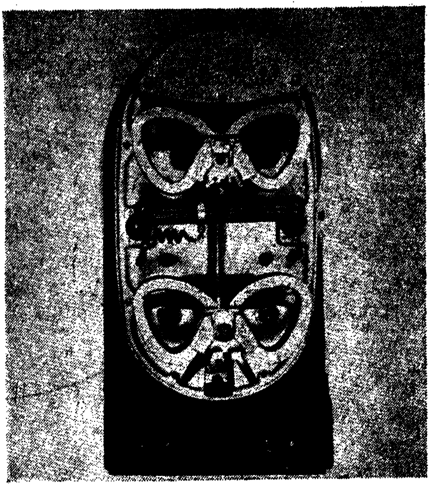


Fig. 6-21. Watthour Meter with Resistor Compensation for Core Loss (Consolidated Edison Company of New York, Inc.)

The value of the fixed resistor R, required to measure core losses, is determined by the following equation:

$$R = \frac{E^2 \times N_v \times N_c}{L_i \times 1000} \text{ ohms}$$

where E = normal secondary meter voltage at which the meter operates
N_v = ratio of potential transformer
N_c = ratio of current transformer
L_i = core losses of transformer bank in kilowatts at normal secondary meter voltage E

Where L_i is known for some voltage E_0 other than E, its value at E may be derived as follows:

$$L_i = \frac{E^2}{E_0^2} \times L_{i_{(E_0)}} \text{ where } L_{i_{(E_0)}} = \text{kilowatt core losses at voltage } E_0.$$

Example:

Transformer bank rating in kva = 4500
Transformer bank voltage rating = 28800/2400
Primary operating voltage = 27600
Secondary operating voltage = 2300
Ratio of potential transformers (N_v) = 20/1
Ratio of current transformers (N_c) = 240/1
Normal secondary meter voltage (E) = 2300/20 = 115

Core losses ($L_{i_{(E_0)}}$) in kw at rated voltage E_0 (2400/20 = 120 v) = 12.49

The core losses (L_i) in kw at normal secondary meter voltage E is therefore equal to

$$\frac{(115)^2}{(120)^2} \times 12.49 = 11.47$$

hence

$$R = \frac{(115)^2 \times 20 \times 240}{11.47 \times 1000} = 5533 \text{ ohms}$$

Resistor R will therefore be set at a fixed value of 5533 ohms, and thereafter be left unchanged. Fig. 6-21 shows such a resistor installed in the watthour meter.

In order to adjust the watthour meter to include core and copper losses a correction equivalent to these losses is applied to the correct number of base revolutions of the portable standard watthour meter. This correction is obtained by multiplying the correct number of base revolutions of the portable standard meter (without regard to the resistor or to the adjustment to be made for copper losses) by a constant K, and adding the revolutions so obtained to the base number of portable standard watthour meter revolutions at each load point to obtain the corrected number of base revolutions.

The constant K may be calculated prior to the meter installation and then used in all subsequent tests. It is derived as follows:

$$K = \frac{\text{kw copper losses}}{\text{kw test load}} + \frac{\text{kw core losses}}{\text{kw test load}}$$

$$= \frac{\left(\frac{SF}{100}\right)^2 \times L_c}{\frac{SF}{100} \times T \cos\theta} + \frac{L_i}{\frac{SF}{100} \times T \cos\theta}$$

$$= \frac{1}{T \cos\theta}\left[\frac{SFL_c}{100} + \frac{100\,L_i}{SF}\right]$$

where S = test load in per cent of meter kva rating
F = ratio of meter kva rating to transformer bank kva rating
T = transformer bank kva rating at full load
$\cos\theta$ = power factor of load for which meter is to be adjusted
L_c = copper losses in kw of transformer bank at full load
L_i = core losses in kw of transformer bank at normal secondary meter voltage E.

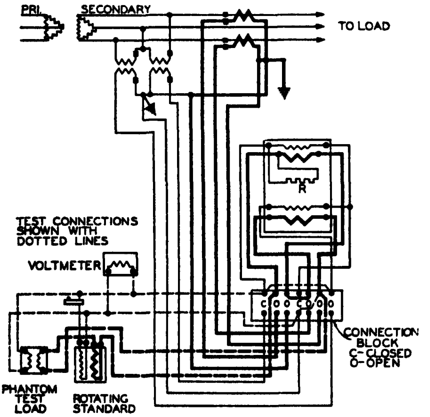


Fig. 6-22. Test Connections for Watthour Meter with Resistor Compensation for Core Loss (Consolidated Edison Company of New York, Inc.)

The value of K should be derived for each test load (value of S) to be used at the normal secondary meter voltage E. It may also be derived for one or more voltages above and below the normal secondary voltage. The value of L_i will vary with the secondary voltage for which the constant K is being computed in accordance with formula $L_i = \frac{E^2}{E_0^2} \times L_{i(E_0)}$.

Theoretically, the proper value of K for the secondary meter voltage found at time of test should be used, although for practical purposes variations in the value of K may be ignored. The test connections are shown in Fig. 6-22.

Example:

T = transformer bank kva rating at full load = 4500

$\cos\theta$ = power factor of load for which meter is to be adjusted = 0.8

$$F = \frac{\text{meter kva rating*}}{\text{trans. bank kva rating}} = \frac{1200 \times 2300 \times 2}{4500 \times 1000} = \frac{5520}{4500} = 1.23$$

S = per cent test load (10% load—light load) = 10.

S = per cent test load (80% load—heavy load) = 80.

L_c = copper losses in kw of transformer bank at full load = 23.6

L_t = core losses in kw of transformer bank = 11.47

* Primary Rating of Watthour Meter is 1200 amperes, 2300 volts, 2 elements.

hence

$$K \text{ (at 10\% test load, } S = 10) = \frac{1}{4500 \times 0.8}\left[\frac{10 \times 1.23 \times 23.6}{100} + \frac{100 \times 11.47}{10 \times 1.23}\right] = 0.027$$

$$K \text{ (at 80\% test load, } S = 80) = \frac{1}{4500 \times 0.8}\left[\frac{80 \times 1.23 \times 23.6}{100} + \frac{100 \times 11.47}{80 \times 1.23}\right] = 0.0097$$

To obtain corrected number of base revolutions of the portable standard watthour meter:

10% Meter Test Load—Assuming base number of revolutions of standard meter as 10, the correction to be applied is equal to 10 × 0.027 or 0.27 revolution. The corrected number of base revolutions of the standard meter is then equal to $10 - 0.27 = 9.73$ revolutions.

80% Meter Test Load—Assuming base number of revolutions of standard meter as 20, the correction to be applied is equal to 20 × 0.0097 or 0.19 revolution. The corrected number of base revolutions of the standard meter is then equal to $20 - 0.19 = 19.81$ revolutions.

Summary

The methods described in this section are useful as compared with metering on the high-voltage side:

When the metering cost is appreciably lower than for metering on the high-voltage side.

For exposed locations on the system, where high-voltage instrument transformer equipment may be expected to be troublesome because of lightning or other disturbances.

When the limited available space makes the installation of high-voltage metering equipment difficult, hence more expensive.

When a customer with a rate for low-voltage service is changed to a high-voltage service rate.

Generally speaking, metering on the high-voltage side should be preferred:

Where the cost of high-voltage metering is lower than for methods with loss compensation.

Where multiple low-voltage metering installations are necessary in place of one metering equipment on the high-voltage side.

Primary metering is necessary where a part of the load is used or distributed at the supply voltage.

Between the compensating meter and the transformer-loss compensator, the advantages of the former are:

Iron losses are registered at no-load, regardless of how small they are.

The load measurement on the low-voltage side by the conventional watthour meter is available as a separate quantity from the losses.

The disadvantages of the compensating meter are:

Two meters are used, whereas primary metering requires only one.

This complicates the determination of maximum demand.

Special test equipment, not ordinarily carried by meter testers, is required.

Some of the other methods overcome the objections of the compensating meter in that there is only one meter for a single-transformer-bank installation, and the same test equipment as used for watthour meters may be used for calibration and tests. Their disadvantage, as related to the compensating meter, is that where iron losses are low (below the starting load of the meter) they will not be registered at times of no load. Experience indicates that this condition is relatively rare, and it applies equally to metering on the high-voltage side. The limitations of the other methods are discussed in the paragraphs relating to them.

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MEASUREMENT OF INTEGRATED LINE LOSSES

It is sometimes desirable to integrate the losses in a transmission line or in a cable over a period of time. Since line losses vary with the relation of I^2R; where I is the line current and R is the resistance of the line, such a measurement may be made with an ampere-square-hour meter whose readings are multiplied by a constant equivalent to the resistance of the line.

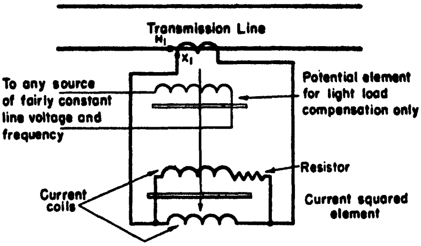

Transmission Line
H_1
X_1
To any source of fairly constant line voltage and frequency
Potential element for light load compensation only
Resistor
Current coils
Current squared element

Fig. 6-23. Typical Connections for an Ampere-square-hour Meter

The ampere-square-hour meter is an induction type meter similar to a watthour meter, and is used to measure current squared with respect to time. When the resistance constants of a power transmission line are known, they may be multiplied by the ampere-square-hours to integrate the watt loss in the line I^2Rt. The first meters of this type were used where two power companies used a transmission line jointly and it was necessary to apportion the cost equitably between them.

In general, the construction consists of a two-element meter, in which one element has only a watthour meter potential coil for light-load compensation and a second torque-producing element responsive to current squared. Fig. 6-23. The current enters the meter and divides, part going through a special current coil mounted on the iron usually occupied by a potential winding, and the remainder going through a current coil in series with a resistor having a zero temperature coefficient. The split current circuit with resistance in one path results in a torque proportional to the square of the current passing through the meter. The line-resistance constant may be used as a register multiplier or may be included in the meter register ratio.

For ampere-square-hours

$$\text{register ratio} = \frac{360\,K_r}{(t \text{ sec per disk rev})(I^2)}$$

where K_r = register constant,
and I = primary line current.

When an ampere-square-hour meter is connected to the secondary of a current transformer, the multiplier is the *square* of the transformer ratio.

For kilowatthours line losses

$$\text{register ratio} = \frac{360\ K_r\ 1000}{(t \text{ sec per disk rev})(I^2R \text{ line})}$$

When the line losses are included in the register ratio, the register dial records losses directly in kilowatthours and is so read.

The following calculations are required to calibrate the meter for the correct timing of the disk.

The meter torque, and consequently the meter speed, is proportional to the square of the current.

Let T_1 represent the time required for one revolution of the disk at I_1 (or rated amperes) and T_2 represent the time required for one revolution of the disk at I_2 amperes (any current).

I_1 = rated amperes.
I_2 = any operating current.

then $T_2 = T_1 \left(\frac{I_1}{I_2}\right)^2$

Example:

given $T_1 = 4.32$ seconds
$I_1 = 5$ amperes
$T_2 = 4.32 \times \left(\frac{25}{I^2}\right)$

The timing tabulation for a test with an ammeter would appear as follows:

Current (amperes)	*Theoretical Seconds per Disk Revolution*	*Per cent Full-load Speed*
1	108	4.0
2	27	16.0
3	12	36.0
4	6.75	64.0
5	4.32	100.0
6	3.0	144.0

$$\text{per cent registration} = \frac{\text{meter amperes squared}}{\text{true amperes squared}} \times 100$$

An ampere-square-hour meter may be calibrated also by calculating the copper loss for full load on the meter and using the method described in the preceding part of this section for calibrating the copper-loss element of a compensating meter. Also a compensating meter, Fig. 6-12, may be used as an ampere-square-hour meter by omitting the connection to the load side of the current coil of the *E* element.

LOAD TOTALIZATION

Electric totalization may be desired in terms of kilowatts, kilowatthours, integrated kilowatt demand, or in the related quantities of kva and kvars. Of these the integrated quantities, that is, kilowatthours, kilowatt demand, kilovolt-ampere demand, etc., are normally associated with rates and billing, but are also used for load-limiting and load-dispatching purposes. Totalization of kilowatts has its principal application in power-plant operation and load dispatching. Only totalization of integrated quantities will be treated here.

Uses for Totalizing Devices—For the determination of total kilowatthours only, for any group of circuits or feeders, there is at present no easier and more accurate method than the use of separate watthour meters in each circuit. This involves the reading of the several meters and a simple arithmetical addition to determine the total kilowatthours.

When conditions require that simultaneous demand of a group of circuits be determined or when, for some other reason, such as differential (plus and minus) totalization, it is essential that the total output be registered on a single dial, the problem presented is very different. In such cases, some form of totalizing or summation device may have to be employed.

Demand totalization can be accomplished without the use of totalizing devices. If recording demand meters are used for each individual circuit, it follows that the totalized demand can be obtained by arithmetical addition for each demand interval of the demands of the separate circuits. This method requires that the timing mechanisms of the demand meters remain in synchronism.

Methods—The method or combination of methods to be employed depends largely on the conditions to be satisfied. The number of circuits involved, location of metering points, ratings of the various circuits, etc., are some of the factors which must be considered in making the selection.

For any given installation certain types of devices and methods are eliminated because of the circuit and system conditions. Others may have to be discarded because of inherent limitations in, for example, accuracy or reliability.

For some installations an indication of the monthly maximum demand will suffice. For others the size and importance of the load require a record of the demand for each demand interval. Finally, the basic accuracy of the device or devices, their relative simplicity of construction, and the factors of safety incorporated in their design must be considered.

When the metering points are comparatively close together there is involved what may be termed local totalization. Additional factors are introduced when the metering points are remotely located. The problem may be further complicated where an interchange of power is involved. This alone may dictate the use of totalizing equipment, even though only kilowatthours are to be determined.

Local Totalization

The various methods and devices for local totalization are divided into three major groups which may be designated as follows:

Electrical Totalization—This is totalization of electrical quantities by such methods as the paralleling of the secondaries of current transformers, or the thermal converter.

Mechanical Totalization — In this group fall those methods which involve combining on one watthour meter shaft, or by mechanical gearing to one registering unit, a number of watthour-meter elements.

Impulse Totalization—This consists of equipping individual watthour meters with contact devices and by various methods totalizing the impulses produced by these contact devices.

In some installations, the best solution may involve a combination of all three groups.

Electrical Totalization—Where conditions permit, the use of this method affords a low-cost solution to the problem. Totalization is accomplished on one watthour meter. Therefore, to obtain the totalized demand the meter need only be equipped with a demand-meter register, or a contact device to operate an impulse-operated demand meter.

When this method is used, care must be exercised to insure potential excitation to the watthour meter as long as any one of the totalized circuits is energized. The customary practice is, therefore, to obtain the potential excitation directly from the busbars, rather than from an individual feeder circuit. Where such a practice cannot be followed, so-called transfer relays may be employed to transfer automatically the potential excitation from a dead to a live circuit.

Paralleling Current-Transformer Secondaries—Fig. 6-24 utilizes standard equipment with minimum operating

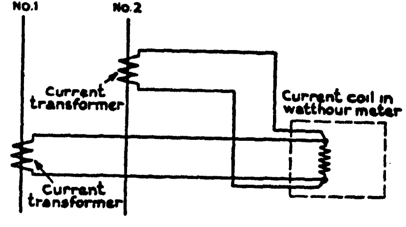


Fig. 6-24. Simplified Connection Diagram for Paralleled Connections of Current-Transformer Secondaries

and maintenance costs. It requires that the following circuit conditions be satisfied:

That the feeders must have a common voltage and frequency, as for example, those instances in which they terminate on one set of busbars.

That the number of circuits or feeders is not more than 2 or 3.

That the ratio of the current transformers is the same for all feeders.

The obtainable accuracy from totalization by parallel current-transformer secondaries is generally satisfactory. If modern current transformers with high accuracy are employed and if they are not heavily loaded, the overall accuracy should be within one per cent. The possible sources of errors are: in the watthour meter, in the current transformers, and in shunting part of the total secondary current around the watthour meter.

The possible errors in the watthour meter, as compared with those encountered when separate watthour meters are used for each circuit, are due to the fact that the watthour meter must operate over a much wider range of loads. The meter rating must be chosen for the total maximum load (maximum total secondary current) and therefore, will be higher than for separate watthour meters. Yet the meter may be called upon to operate on the minimum load of one circuit.

Errors in the current transformers would result from an increased external burden on the transformers. Normally the opposite is the case, because the meter would have a higher self-contained rating, but even if the volt-ampere burden should be increased, by not increasing the rating of the meter over that used for separate watthour meters, the effect usually will be small. The reason is that the internal burden of the current transformer is in the order of 25 to 50 volt-amperes in comparison with a burden of approximately 1.3-volt-amperes for a watthour meter for use with 5-ampere secondary current transformers. Therefore, the percentage change in the external burden may be considerable without appreciable effect on the accuracy.

Since the principal purpose of paralleling the secondaries of the current transformers is to obtain totalization, the accuracy of the individual secondary currents is of lesser importance. If an individual current transformer is operating near its rated capacity the accuracy compares with that of the total secondary current. On the other hand, for very light loads, appreciable errors (in per cent) may be encountered. These errors result from the relatively high voltage across the common burden, requiring an induced voltage and exciting current in the current transformer much higher than would normally be required for the light load.

The third source of errors is encountered when the primary of one transformer is disconnected or carries no current. The secondary of the transformer then acts as a shunt across the current coil of the watthour meter. As a result, part of the current to the watthour meter is shunted around that meter. This shunted current is the magnetizing current for the dead transformer.

The errors are functions of the magnitude of the magnetizing current and also the phase angle of the common burden (the current coil in the watthour meter). The magnitude of the magnetizing current depends on the construction of the dead current transformer and the voltage impressed on it. As related to the exciting current in a live current transformer under normal conditions, the magnetizing current is much smaller, and when modern current transformers are used, and when the common burden is reasonably low, the magnitude of these errors is quite small.

As an example, two current transformers with 5-ampere secondaries may be connected in parallel. The common burden may consist of three watthour meter current coils connected in series. If these coils are rated for a total secondary current of 10 amperes, a representative total impedance will be $0.014 \times 3 = 0.042$ ohms. The total burden is therefore $0.042 \times 10 \times 10 =$ approximately 4 volt-amperes, or 2 volt-amperes on each transformer.

In case one of the transformers is dead and the other operates at 100 per cent load, the voltage across the common burden is 0.042 × 5 = approximately 0.2 volts, which will result in a magnetizing current of about 0.002 ampere, or approximately 0.04 per cent of the 5 amperes through the meter.

The importance of keeping the common burden low is thus apparent. One way of reducing this burden is to parallel at the meter terminals rather than at the secondary terminals of the transformers. When the leads are short and their burden only a few volt-amperes, it is immaterial where the paralleling is done, but to avoid difficulties where long leads with higher burdens are involved, it is well to establish the general rule of paralleling at the meter terminals.

Totalization by paralleled current-transformer secondaries affords a low-cost solution to the problem where the limitations of the method permit its use. Standard equipment is used and, therefore, operating and maintenance costs are at a minimum.

Special conditions are encountered where the secondaries of current transformers cannot be paralleled because relays and protective devices are operated from the same transformers and prohibit interconnections.

Totalizing Transformers—If the ratio of the current transformers is not the same for all feeders, it may still be possible to totalize by paralleling the secondaries of current transformers. So-called totalizing transformers can be employed to step the secondary currents down, and thereby provide the required overall current-transformer ratio. An example of this is shown in Fig. 6-25. Arrangements which require the secondary current to be stepped up, because of the resultant increase in the burden on the current transformer, should be avoided.

Totalizing transformers should be eliminated if possible because they introduce additional errors. For one reason, these transformers have inherent errors which are quite likely to add to the other errors. Furthermore, such transformers usually comprise relatively large burdens (from 25 to 50 volt-amperes) and these are imposed on the current transformer with resultant increases in the errors. The inherent errors in totalizing transformers usually relate inversely to their burden, thus small errors mean high inherent burdens, and vice versa.

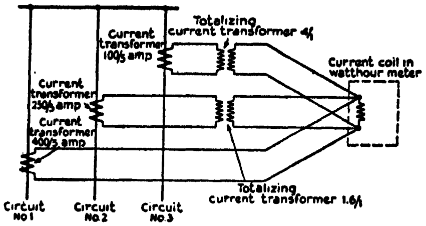

Totalizing current transformer 4/1
Current transformer 100/5 amp
Current coil in watthour meter
Current transformer 250/5 amp
Current transformer 400/5 amp
Totalizing current transformer 1.6/1
Circuit No 1
Circuit No.2
Circuit No.3

Fig. 6-25. Simplified Connection Diagram Showing Use of Totalizing Current Transformers

Totalizing transformers can often be eliminated by the use of semistandard current transformers. As an example, the load on one circuit may be such as to require a transformer with a 50-ampere primary rating. For the other circuits to be totalized, the current transformers may be rated 200/5 amperes, ratio 40/1. The 50-ampere transformer instead of the standard rating of 50/5 amperes, ratio 10/1, can be rated 50/1.25 amperes with a ratio of 40/1, and its secondary can then be paralleled directly with the secondaries of the other transformers.

Multiple Current Windings — This method uses a watthour meter in which each meter element has one current winding for each circuit to be totalized, Fig. 6-26. The circuits to be totalized must have a common voltage and frequency, and all current transformer ratios must be equal. The obtainable accuracy from totalization by multiple windings is generally satisfactory. As with parallel current-transformer secondaries, the errors in the watthour meter due to the increased load-diversity factor are present.

The effect of a dead current trans-

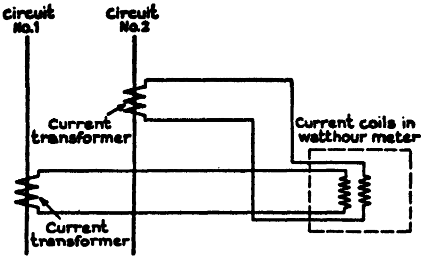


Fig. 6-26. Simplified Connection Diagram for Watthour Meter with Two Current Circuits per Element

former on accuracy is, for practical purposes, nil. The winding connected to the dead transformer acts as a lagging coil on the meter, but the impedance of the circuit is generally so high (in excess of 100 ohms), that the induced voltage cannot produce an appreciable lagging current.

Thermal Converters—The thermal converter, also termed *thermal transmitter,* when connected into an alternating-current circuit produces a direct-current voltage which is directly proportional to the power in the alternating-current circuit. The direct-current output is measured by a potentiometer recorder which is a null method. The demands of circuits at a number of divergent points may be totalized. One or more of the transmitters may be reversed to subtract from the total. Interchange power may be recorded as the transmitters are accurate with power flow in either direction. This method is suitable also for *differential totalization.* The direct current output is time lagged in the same manner as a thermal demand meter. The method is used principally for determining the totalized demand of a number of circuits.

Mechanical Totalization—Mechanical totalizing is in common use for the totalization of power and lighting circuits. A three-element meter, for example, will totalize one three-wire, three-phase power circuit plus one single-phase lighting circuit, either three- or two-wire.

The mechanical totalization can be extended to include other combinations within the scope of two- and three-element watthour meters. In determining the suitability of such meters, consideration must be given not only to the number of elements required for the totalization, but also to the number of meter terminals.

For special problems, multiple-element totalizing watthour meters are available with as many as 24 elements. An 8-element totalizing watthour meter is shown in Fig. 6-27. The use of such totalizing watthour meters is confined to those installations where current transformers are used and where the circuits to be totalized are so located with respect to one another that the secondaries of the current transformers from each circuit can be carried to a common point where the totalizing meter is to be installed, without imposing excessive burdens on the current transformers.

In order that each meter element may be made to exert a torque on the

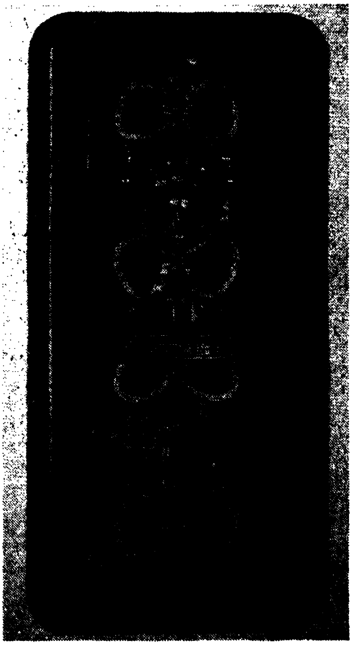


Fig. 6-27. Eight-element, Four-circuit Totalizing Watthour Meter with Cumulative Demand Register and Demand Contacts, Type VSMW-5 (General Electric Co.)

meter shaft proportional to the primary power in the circuit, the number of turns of the current windings may be made to differ. From a practical point of view, however, the limits are approximately 5 to 1.

Totalizing watthour meters offer the advantage of requiring less switchboard space than individual watthour meters for each circuit plus totalizing equipment. This may be a determining factor. However, because of their special construction, high cost, and the considerable time required to calibrate and test them, the multiple-element totalizing watthour meters are used generally only for special problems as, for example, unusual combination differential and totalizing metering.

Impulse Totalization—This method is highly flexible in its applications and is particularly well-suited where the circuits to be totalized already have watthour meters installed, because these meters need not be changed but require only the installation of suitable contact devices.

Other applications are those in which the circuits to be totalized either are too numerous or too far apart to permit the use of electrical or mechanical totalizing methods. The problem may also be one of totalizing a-c and d-c circuits.

The individual watthour meters are equipped with suitable contact devices to produce impulses to represent kilowatthours. These impulses are transmitted to a totalizing device. For each circuit a conventional arrangement of operating coil, armature, and advancing pawl, or the equivalent, is used to convert impulses to mechanical rotation. This rotation can then be totalized by mechanical means, such as a summation mechanism, also frequently referred to as a differential. The final ring gear (summation gear) may drive a demand mechanism directly, in which case the totalizing device is a combination of a totalizing relay and a demand meter. It may also drive an outgoing contact device to produce impulses in direct proportion to the number of incoming impulses. The outgoing contact device will then be connected to an impulse-operated demand meter, or to one circuit of another totalizing device.

The several ways in which impulse totalization can be accomplished are divided into two classes, those which function on the two-wire principle of operation, and those which function on the three-wire principle of operation. As the transmission of impulses is a vital part of the totalization, due consideration should be given the advantages of three-wire operation.

The choice of the scheme or device depends largely on the size, number of circuits, and importance of the installation.

The source of excitation through the contact devices is independent of the meter circuit proper and should be chosen so that it can be maintained as long as any one of the totalized circuits is energized. Excitation directly from busbars is therefore preferable, but if this cannot be permitted, use can be made of transfer relays to transfer the excitation from one circuit to another in case the first circuit is de-energized.

If there is a choice between a-c or d-c excitation, the former is usually preferable, because it permits the use of synchronous motors in or with the demand meters for time-keeping purposes.

With impulse totalization, proper engineering and application of devices are essential to keep possible so-called storage errors at negligible values. As an example of storage errors a watthour meter may have integrated almost enough kilowatthours to produce one impulse, but just before the impulse is made the demand interval ends and the impulse is then carried over to the following demand interval, whereas almost all of it belongs in the interval just ended. Thus it is possible to lose almost one impulse at the end of the demand interval, and similarly to gain almost one impulse at the beginning of the interval. The two possible errors tend to cancel; therefore, the maximum possible error is less than one impulse.

Storage errors are possible in the

outgoing contact device in totalizing relays or totalizers, and the possible storage errors in totalizing relays and totalizers are individually of greater significance because of the greater value of each impulse. However, when proper devices are used and correctly applied the effect of storage errors on the overall accuracy of the totalizing equipment is, for practical purposes, negligible. Obviously a minimum of contact devices should be used, both in watthour meters and totalizers or totalizing relays. Thus, cascading or pyramiding of totalizers should be avoided. Fig. 6-28.

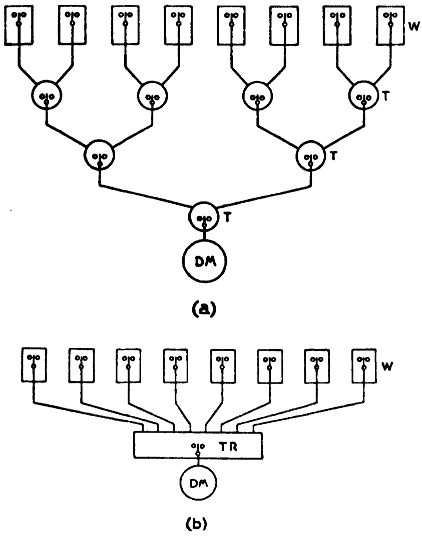


Fig. 6-28. Line Diagram Illustrating Methods of Impulse Totalization
(a) Totalization by cascading two-circuit devices.
(b) Preferred method using one eight-circuit totalizing relay.
W—Watthour meter with contact device
T—Two-circuit totalizer
TR—Eight-circuit totalizing relay
DM—Impulse-operated demand meters

The most satisfactory arrangement from the standpoint of high accuracy is one in which the value of each of the impulses is kept as low as is practical in the initial stages of totalization. The value of each of the impulses to the final demand meter depends upon the size of the load and the number of impulses corresponding to full-scale deflection of the demand meter. In this respect, therefore, a demand meter with a high number of impulses for full scale is to be preferred because of the lower value for each impulse and the smaller possible storage error.

There are practical limitations to the number of impulses corresponding to full scale of the demand meter. Aside from the fact that the device which produces the impulses is limited to a maximum rate of impulses, the responsiveness of the demand meter also imposes limitations. A high number of impulses may mean, in addition, a greater angular deflection from zero to full scale which in turn may increase the time required for the demand meter to reset at the end of the demand interval. The life of the moving members also is affected. Demand meters on medium and large loads commonly have 200, 300 or 400 impulses for full-scale deflection.

Duplex Principle—It is possible to obtain totalized maximum demand of two circuits directly on a duplex form of demand meter as is shown in Fig. 14-42(b). The demand meter may be either indicating or graphic. The two-wire contact devices are used in the two watthour meters. These are connected to the duplex advancing coil in the demand meter. This method is practical for such small values of kilowatt demand as those which, for economic reasons, dictate a minimum cost of equipment.

Two-Position Contact Devices — A simplex form of impulse-operated demand meter (single advancing coil) may be used to obtain totalized demand from two metered circuits if the two watthour meters are equipped with two-position contact devices. The connections are shown in Fig. 14-42(a). The demand meter must be suitable for two-wire operation. However, as impulses may be lost from simultaneous make or break operation of the contact devices, the application is limited to small installations where the least costly equipment must be used.

Two-Circuit Totalizers and Recording Demand Meters—Two-circuit totalizers that may be equipped with kilowatthour registers, watthour demand registers or outgoing demand contacts are shown in Figs. 14-45, 14-48, and 16-25. Two-circuit recording demand meters are shown in Figs. 14-35 and 16-26. Figs. 14-42, 14-46 and 14-47 show diagrams of typical totalizing schemes.

Multiple-Circuit Totalizing Relays—For the larger installations, multiple circuit totalizing relays may be used with demand meters. They may be equipped with 2, 3, 4, 6 or 8 elements. Figs. 14-44, 16-30 and 16-31 show typical totalizing relays.

Differential Totalization

Kilowatthour Measurements—In interconnected power systems it is often desirable to measure *in* and *out* energy or demand, or both.

In a simple interconnection, as illustrated in Fig. 6-29, two ratcheted watthour meters will measure the interchange of kilowatthours. Watthour meter A will register only for *out* power and watthour meter B only for *in* power. The difference between the two readings will show the net interchange.

When the interchange point comprises several lines, as in Fig. 6-30, the measurement of the same quantities is more complicated. The measurement of the excess kilowatthours of East over West or West over East, can be accomplished by the separate watthour meters—that is, excess kilowatthours:

East over West = $(A + C) - (B + D)$
West over East = $(B + D) - (A + C)$

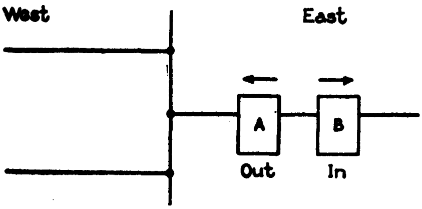


Fig. 6-29. Diagram Illustrating Meters for Differential Metering of One Line

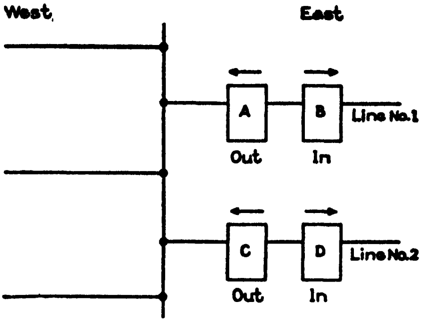


Fig. 6-30. Diagram Illustrating Meters for Differential Metering of Two Lines

The quantity of *net* kilowatthours furnished by either East or West can be measured, but involves totalizing equipment. Net kilowatthours furnished by East is the integration of kilowatthours from the net kilowatt power of East over West. Such an integration of necessity may be intermittent, as no integration will take place when the net kilowatt power is from West to East. What is required is a combination of additive and subtractive totalization of the four watthour meters, A, B, C, and D. The sum of B plus D must be subtracted from the sum of A plus C.

Kilowatt Demand—Demand measurements generally involve only one quantity, namely the one associated with net kilowatthours furnished from West to East or vice versa. It, therefore, requires the same basic totalizing equipment as for net kilowatthours. For the recommended methods of demand metering, should the net kilowatt power change from positive to negative during a demand interval, the net negative integration will not be deducted from the demand already established by the net positive integration.

Var Measurements—If differential metering includes varhours, the problem is further complicated because four quantities may then be involved, namely, leading varhours *in* or *out*, and lagging varhours *in* or *out*. Each power line may, therefore, in addition to the two watthour meters, have four varhour meters, all of which must be ratcheted to permit forward direction of rotation only.

The ratchet will prevent, for example, the *out* varhour meter for lagging power factor from rotating backward for *out* leading power factor, but without additional equipment the meter cannot differentiate between *out* lagging power factor and *in* leading power factor. Fig. 6-31 illustrates this more clearly. Each of the four meters should measure only in their respective quadrant. In the case of the *out* varhour meter for lagging power factor, the quadrant is No. 4. The ratchet on the meter operates to prevent rotation in the quadrants above the horizontal center line, namely in quadrants 1 and 2. Additional equipment is required to prevent rotation in quadrant 3.

This additional equipment generally takes the form of a power-directional relay in conjunction with a multipole relay. Through these the potential excitations to the meters are controlled. With *in* power, only the *in* meters are energized (quadrants 2 and 3) and with *out* power, only meters in quadrants 4 and 1 are energized. Thus the ratchets operate along the horizontal center line and the power-directional relay along the vertical center line.

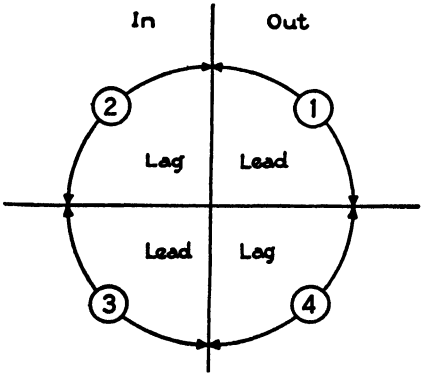


Fig. 6-31. Chart Illustrating the Four Quantities in Differential Varhour Metering

Another way of visualizing this is to analyze the system conditions from the standpoint of two separate and independent classes of power. One may be designated as active power, or kilowatts. It originates in the prime movers. The other is reactive power in kilovars. It can be supplied by increasing the field excitation of generators or synchronous condensers, or by the addition of static capacitors to the system.

When kilovars are considered as another class of power, it too may flow *in* or *out* through the interconnection, and viewed in this manner there are only two quantities involved, as in the case of kilowatts.

If it is established by convention that kilowatts *out* shall designate kilowatts which are produced (as contrasted to kilowatts which are consumed) it can be similarly established that *out* kilovars shall designate reactive power which is also produced. In terms of lead or lag this then corresponds to lagging kilovars *out*. Likewise, *in* kilovars correspond to lagging kilovars *in*. These two quantities (*in* and *out* kilovars) can be measured on two ratcheted varhour meters without the use of a power-directional relay.

If it is necessary to relate the direction of kilovars to the simultaneously existing direction of kilowatts, there are again four kilovar quantities involved, as will be noted from Fig. 6-32. Obviously, kilovars *out* is the same quantity whether referred to as "kilovars lead *in*" or "kilovars lag *out*." The difference is simply that for one designation the simultaneous direction of kilowatts is *in*, whereas it is *out* for the other designation.

Electrical Totalization — Where the conditions permit, electrical totalization is the preferred scheme. Subtraction instead of addition can readily be accomplished by simply reversing the connections of the secondaries of the current transformers.

Where the conditions are such that the net totalized value may at times be positive and at other times negative, it is necessary to employ two ratcheted watthour meters, one for net positive kilowatthours, and the other for net negative kilowatthours. Should it be desired to obtain net results on

Kilowatts IN ←	Kilowatts OUT →
Kilovars IN ← (Lag IN)	Kilovars IN ← (Lead OUT)
Kilovars OUT → (Lead IN)	Kilovars OUT → (Lag OUT)

Fig. 6-32. Direction of Kilovars Related to Direction of Kilowatts

one set of dials, impulse totalization can be employed. A double-shaft, ratcheted meter may also be used. This arrangement is considered later under *Mechanical Totalization.*

Impulse Totalization—The devices described previously for impulse totalization can be modified to accomplish subtractive totalization.

The usual arrangement is to modify the devices so that one or more of the circuits are *subtractive.* Such an arrangement is entirely practical but there are limitations to the quantity of *subtractive* power that can be handled.

For example, let it be assumed that the *in* kilowatts are equal to the *out* kilowatts. The net kilowatthours are then zero. However, this does not mean that the totalizing device will not receive impulses. The *in* and *out* meters will both produce impulses, and the totalizing device will receive *in* and *out* impulses alternately. As under this condition the impulses must not cause the register or outgoing contact device to rotate, it can be appreciated that some sort of free coupling must be included to give a free play corresponding to at least one impulse. For some conditions, a satisfactory arrangement would consist of the use of a ratchet with few teeth, each tooth equal to at least one impulse. In other cases a free coupling must be included ahead of the ratchet, with the free play corresponding to the desired number of impulses.

A free play corresponding to one impulse may not suffice. For example, the *in* and *out* power may be totalized on separate totalizing devices. These in turn may send impulses to a final totalizing device with one circuit additive and one circuit subtractive. For zero net power the final totalizing device may then receive several *in* impulses in succession, followed by several *out* impulses.

The free play should be made as small as can be permitted because it introduces a possible source of error. The magnitude of the error depends on the position of the driving pin in the free coupling at time of change in direction of the net power. The maximum possible error is the full free play of the coupling.

Two-Circuit Totalizers—Some totalizers, for example the type MD-3, Fig. 14-48, can be arranged so that one circuit is subtractive. It is then identified as type MD-4. One circuit is made subtractive by reversing the rotation of one of the synchronous motors. At the same time, the cams and brushes associated with the motor are changed to be suitable for the reverse rotation. The gearing to the cyclometer impulse counter is likewise changed.

If the totalizer is used to obtain the net kilowatthour reading on one set of dials, it can be equipped with an ordinary kilowatthour register. The pointers of the register will then rotate forward for positive power and backward for negative power, and the difference between successive readings will give excess kilowatthours of East over West, or West over East, depending on whether the pointers have moved forward or backward.

For the measurement of net kilowatthours or demand in one direction only, the totalizer may be equipped with a ratcheted register, or ratcheted outgoing contact device.

Multiple-Circuit Totalizing Relays—Some multiple-circuit totalizing relays, as for example the type shown in Fig. 14-44, can be modified to provide subtractive circuits. The subtractive circuits must, however, be in pairs. If, for instance, there were required three additive and one subtractive circuits, it would be necessary to use a relay with two subtractive circuits. Since the relays are made in two-, four-, six-, and eight-circuit construction only, a six-circuit relay would have to be chosen. There would be one extra additive and one extra subtractive circuit. While unused, these should have one coil of each circuit energized continuously, or should be blocked.

Such multiple-circuit totalizing relays must also be equipped with a free coupling when used to determine differential kilowatthours or demand. Furthermore, as the outgoing contact device is driven through a spring, it can be rotated in the forward direction only. If there is a likelihood of the negative power exceeding the positive power and thereby causing the cam shaft to rotate backward, the cam shaft should be equipped with a ratchet to prevent the cams from backing up against the brushes and possibly bending them out of adjustment.

The spring drive for the outgoing contact device provides assurance that simultaneously received incoming impulses will be sufficiently staggered as outgoing impulses to allow the receiving device to respond to them. As an example, a six-circuit totalizing relay may have a contact ratio of 6 to 1. Therefore, should six impulses be received simultaneously, the outgoing contact device will be advanced sufficiently to produce one outgoing impulse. Without the spring drive and damping device this outgoing impulse may be produced so fast that its duration will be insufficient to allow the receiving device to respond to it. On the other hand, if the totalizing relay has a contact ratio greater than 6 to 1, simultaneously received impulses for all the circuits will not produce a *complete* outgoing impulse; that is one side of the outgoing contact device will change from open to closed, or vice versa, and the receiving device will have more than ample time to respond.

When the totalizing relay is arranged with one or more subtractive circuits, it is possible to reduce the contact ratio. For instance, a four-circuit totalizing relay may be arranged with two circuits subtractive. If the relay has a contact ratio of 4 to 1 (greater than the number of additive or subtractive circuits) the spring drive may be omitted. This will permit rotating the cam shaft for the outgoing contact device in both directions, so that it may be equipped with two outgoing contact devices, one for net positive demand, and the other for net negative demand. The cam assemblies for the outgoing contact devices must be ratcheted and the cam shaft must include the necessary amount of free play.

These multiple-circuit totalizing relays can be equipped with one kilowatthour register so arranged that the register pointers will move forward for net positive power and backward for net negative power. The spring drive to the outgoing contact device is then replaced by a straight gear drive and the outgoing contact device by the kilowatthour register.

Another modification of this relay is one in which it is equipped with two ratcheted kilowatthour registers in place of the outgoing contact device. One register will record net positive kilowatthours and the other net negative kilowatthours. As the outgoing contact device is omitted, there is no problem of spacing outgoing impulses and the spring drive is therefore replaced by a gear drive incorporating the necessary free play.

Mechanical Totalization—Mechanical totalization can be employed for differential metering. Multiple-element totalizing watthour meters can be so arranged, by simply reversing the external connections, that one or more elements exert negative torque. Where electrical totalization cannot be used, and where the errors from the free coupling in impulse totalizing devices are of appreciable magnitude, the solu-

TABLE

CHARACTERISTICS OF INDIVIDUAL

	DESIGNATION	(A)	(B)	(C)
	TRADE NAME OF SYSTEM	Rectified Current	Torque Balance	Photoelectric Telemeter
	METHOD OF OPERATION	Current	Current	Frequency
1	CHARACTER OF MEASUREMENT PROVIDED			
	Electrical magnitudes			
	D-c amperes		*	*
	A-c amperes	*	*	*
	D-c volts		*	*
	A-c volts	*	*	*
	Watts		*	*
	Volt-amperes		*	*
	Vars		*	*
	Power factor			*
	Phase angle			*
	Frequency			*
	Ampere-hours			
	Watthours			
	Volt-ampere-hours			
	Varhours			
	Demand			
	Nonelectrical magnitudes			
	Levels		*	*
	Positions		*	*
	Pressures		*	*
	Quantities of flow (gal, etc.)			
	Rates of flow (gal per hour, etc.)		*	*
	Temperatures		*	*
2	Continuous or step-by-step action	Continuous	Continuous	Continuous
3	Nature of received measurements { Indication Record Integration	Indication Record	Indication Record	Indication Record
4	Performance			
	Speed of response			
	(*A*) Transmitter (time to reproduce measured magnitude)	Instantaneous	Instantaneous(*a*)	2 sec
	(*B*) Receiver (maximum time for complete response)	Instantaneous	Instantaneous(*a*)	2 sec
	(*C*) Total possible maximum lag in over-all operation	Instantaneous	Instantaneous(*a*)	3 sec
5	Estimate of maximum possible error inherent to system, not including error in primary measuring element	2 per cent(*b*)	1 per cent(*b*)	1 per cent
6	Power requirements			
	(*A*) Nature of power supply (voltage, frequency, etc.)	115 v, 25-60 cyc.	115 v, 25-60 cyc.	115 v, 25-60 cyc.
	(*B*) Point of application of power (trans., rec. or both)	Transmitter	Transmitter	Both
	(*C*) Does operation require synchronism between trans. and rec.?	No	No	No
7	Self-restoring characteristics—will correct measurements be performed after;			
	(*A*) Interruption of power supply?	Yes	Yes	Yes
	(*B*) Temporary disconnection of line circuit?	Yes	Yes	Yes
8	Is system inherently adaptable to totalization of measurements from more than one transmitter?	Yes	Yes	Yes

6-C

TYPES OF TELEMETERS

(D)	(E)	DISTANT DIAL		SELSYN		
Metameter	Remote Demand Metering	D-c Operated	A-c Operated	Excited Receiver	Iron Vane Type Receiver	With Indication Transmitter
Impulse-duration	Impulse-counting	Impulse-counting	Impulse-counting	Position	Position	Position
*				*	*	*
*				*	*	*
*				*	*	*
*				*	*	*
*				*	*	*
*				*	*	*
*				*	*	*
				*	*	*
				*	*	*
	*	*	*			
	*	*	*			
	*	*	*			
	*	*	*			
*(g)	*					
*						
*				*	*	*
*						
*(g)	*	*	*			
*						
*						
Continuous	Step-by-step	Step-by-step	Step-by-step	Continuous	Continuous	Continuous
Indication Record Integration(g)	Indication Record Integration	Integration	Integration	Indication Record	Indication	Indication Record
(Average)						
15 or 5 sec				Instantaneous	Instantaneous	1 sec
15 or 5 sec				Instantaneous	Instantaneous	Instantaneous
15 or 5 sec				Instantaneous	Instantaneous	1 sec
0.5 per cent of full scale	0	0	0	0.5 mech. deg	0.5 mech. deg.	1.0 mech. deg
115 v, 25–60 cyc.	115 volts 25–60 cyc. 125 or 250 v, dc(f)	125 or 250 v, dc(f)	115 v, 25–60 cyc.	115 or 230 v, 25–60 cyc.	115 or 230 v, 25–60 cyc.	115 or 230 v, 25–60 cyc.
Both	Transmitter ac Both for dc	Transmitter	Transmitter	Both	Transmitter only	Both
No	No	No	No	Yes	—	Yes
Yes	Yes, for demand No, for integrated total	No	No	Yes	Yes	Yes
Yes	Yes, for demand No, for integrated total	No	No	Yes	Yes	Yes
Yes	Yes, with aux. relay	No	No	Yes	No	Yes

TABLE 6-C

CHARACTERISTICS OF INDIVIDUAL

	DESIGNATION	(A)	(B)	(C)
	TRADE NAME OF SYSTEM	Rectified Current	Torque Balance	Photoelectric Telemeter
	METHOD OF OPERATION	Current	Current	Frequency
9	Is system inherently adaptable to operation of more than one receiving instrument from a single transmitter?	Yes	Yes	Yes
10	Characteristics affecting line transmission nature of transmitted current (dc, ac, rect. ac, etc.)	Rectified ac	Rectified ac	Audio-frequency
11	(For impulse systems) maximum and minimum impulses per minute			
12	Is neutral or polarized relay employed?	No	No	No
13	Maximum allowable loop resistances, ohms	2500(*c*)	8800(*c*)(*d*)	4000
14	Minimum allowable insulation resistance, megohms	0.5	1.0	0.1
15	Number of conductors in interconnecting circuit	Two	Two	Two
16	Possibility of using ground as a conductor	Not desirable	Not desirable	Yes
17	Possibility of using conductors exposed to high potentials or inductive influence	Not desirable	Not desirable	Yes
18	Possibility of using superposed circuits as conductors: (*A*) Simplexed (*B*) Composited (*C*) Carrier	 Yes Yes No	 Yes Yes No	 Yes Yes Yes
19	Normal line current, milliamperes	0–25	0–8	320
20	Maximum line current on short circuit	25	10	500
21	Maximum open-circuit voltage (*A*) Between wires (*B*) To ground	 125 125	 125 125	 120 120
22	Is additional equipment required to limit noise on adjacent telephone circuits?	No	No	No
23	Brief description of system	Measured quantity rectified by hot-cathode mercury-vapor-filled full-wave rectifier tube, transmitting direct current over the interconnecting circuit	Measuring element directly (or spring-) coupled to restraining element, which measures direct current required to balance torque of operating or measuring element. Direct current supplied by pliotrons con-	The transmitter contains a basic measuring instrument which indicates the quantity to be telemetered. This basic instrument indication is followed photoelectrically by a frequency-meter element which is excited by a variable-frequency oscillator. The signal of the latter is

(Continued)

TYPES OF TELEMETERS

(D)	(E)	DISTANT DIAL		SELSYN		
Metameter	Remote Demand Metering	D-c Operated	A-c Operated	Excited Receiver	Iron Vane Type Receiver	With Indication Transmitter
Impulse-duration	Impulse-counting	Impulse-counting	Impulse-counting	Position	Position	Position
Yes	Yes	Yes	Yes	Yes	Yes	Yes
Any kind	ac, dc, rect. ac, audio or radio frequency	dc or rectified ac	ac	ac	ac	ac
4 per min or 12 per min (constant)	1 per sec max	1 per sec max	1 per sec max	—	—	—
Rarely	Polarized relay (or relays) used for dc	Polarized except for short distances	No	No	No	No
5000	6000	6000	1500	1 ohm per volt per conductor	40 ohms per wire	1500 ohms per wire
0.1	0.1	0.1	0.1	0.1	0.1	0.1
Two	Two	Two	Three	3 or 5	3	3 or 5
Yes	Yes	Yes	Yes	Not recommended	Not recommended	Not recommended
Yes, when insulating transformers are applicable	Yes, when insulating transformers are applicable	Yes, when insulating transformers are applicable	Yes, when insulating transformers are applicable	Yes(*e*)	Yes(*e*)	Yes(*e*)
Yes Yes Yes	Yes Yes Yes	Yes Yes Yes	Yes Yes Yes	Not desirable Not desirable No	Not desirable Not desirable No	Not desirable Not desirable No
40 or 20	50 ac or 25 dc	40	20	10 ma (max) in 3 wires 55 ma in 2 wires (if 5 wires used)	25 (maximum)	10 ma (max) in 3 wires 500 ma (max) in 2 wires (if 5 wires used)
100	350	350	350	50–375	50	600
115 115	115 v ac or 125 or 250 v dc(*f*)	125 or 250 v dc(*f*)	115 115	1 volt per ohm per conductor 0	22 0	55 0
No	No	No	No	Yes, if connecting wires are in same cable as telephone circuit	Yes, if connecting wires are in same cable as telephone circuit	Yes, if connecting wires are in same cable as telephone circuit
A circuit is established, by means of a Telechron motor-driven cam, for a time proportioned to the magnitude being measured, the circuit being interrupted every 15 (or 5) seconds. Another Telechron motor drives the receiving mechanism through a clutch	The number of impulses, which is proportional to the speed of a rotating meter at the transmitting end, actuates the receiving mechanism electromagnets either directly or through polarised relays	The number of impulses of alternate polarity, which number is proportional to the speed of a rotating meter at the transmitting end, either directly or through a polarised relay,	The number of impulses, which is proportional to the speed of a rotating meter at the transmitting end, actuates the receiving mechanism electromagnets of the dis-	Three-circuit Y-connected stator winding (same as miniature three-phase field) salient-pole rotor Transmitting Selsyn geared to shaft of primary element	Three-circuit Y-connected stator winding (same as miniature three-phase field) salient-pole rotor on aluminum shaft, set in jeweled bearings. Transmitting Selsyn geared	Indication transmitter is auxiliary device controlled by instrument-type Selsyn with contacts. Transmitting Selsyn of large commercial type, driven by reversible series motor.

TABLE 6-C

CHARACTERISTICS OF INDIVIDUAL

	DESIGNATION	(A)	(B)	(C)
	TRADE NAME OF SYSTEM	Rectified Current	Torque Balance	Photoelectric Telemeter
	METHOD OF OPERATION	Current	Current	Frequency
23	Brief description of system (continued)		trolled by photoelectric cells, the latter governed by light-beam source deflected by mirror mounted on coupling between elements	transmitted over lines or by carrier current and received at as many stations as desired. The receiver is a frequency meter, the deflection of which may be indicated, recorded, or totalized
24	Reference to published description of system	"Telemetering," by C. H. Linder, C. E. Stewart, H. B. Rex, and A. S. Fitzgerald, *Transactions of A. I. E. E.*, vol. 48, p. 766, July 1929. (1) (9)	"The Torque-balance Telemeter," by A. J. Johnston, *Transactions of A. I. E. E.*, vol. 51, p. 1027, Dec. 1932. (1) (2) (4) (9)	"Tie-line Control with Frequency Bias," by E. L. White, *Electrical West*, vol. 80, p. 132, June 1938. (1) (9)

(*a*) Value increased when transmitter is indicating nonelectrical magnitudes.
(*b*) Maximum error can be reduced by calibration under operating conditions.
(*c*) With one indicating instrument.
(*d*) Can be repeated.

tion may be a multiple-element totalizing watthour meter. As with other watthour meters, the light-load compensation is applied for the forward direction of rotation.

For conditions where it is desired to obtain on one register the net integration, and where the net negative power may exceed the net positive power, a double-shaft ratcheted totalizing watthour meter can be employed. All negative elements will be on one shaft and the positive elements on the other shaft. A differential mechanism combines the rotations of the two shafts; the rotation of the shaft with the negative elements is subtracted from the rotation of the shaft with the positive elements. This arrangement overcomes the limitation of the single-shaft totalizing watthour meter with respect to light-load compensation for backward direction of rotation.

References

General Electric Company—*Load Totalization.* GEA-3126A.
Sangamo Electric Company—*Demand Totalizing with type TDT Thermal Demand Transmitters.*
Manufacturers bulletins and catalog sections.

REMOTE METERING AND TELEMETERING

There is no distinct dividing line between *remote metering* and *telemetering.* Telemetering is defined as the indicating, recording or integrat-

(Continued)

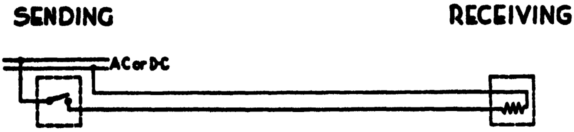
TYPES OF TELEMETERS

(D)	(E)	DISTANT DIAL		SELSYN		
Metameter	Remote Demand Metering	D-c Operated	A-c Operated	Excited Receiver	Iron Vane Type Receiver	With Indication Transmitter
Impulse-duration	Impulse-counting	Impulse-counting	Impulse-counting	Position	Position	Position
system, causing the receiver pen or pointer position to be completely corrected every 15 (or 5) seconds in accordance with the ratio of the duration of the impulses to the duration of the intervals between impulses		causes the polarised armature of the distant dial mechanism to rotate and drive its register	tant dial mechanism to rotate and drive its register	Receiver identical but connected to indicating pointer or recording pen	to shaft of primary element Receiver has identical stator but, uses iron-vane rotor with with indicating pointer	May be used to control a receiver of any of the types listed
"Telemetering and Totalising," by Perry A. Borden and M. F. Behar, *Instruments*, vol. 9, p. 11, January 1936.	"Load Totalization; Part III (Remote Metering)," by E. J. Boland, *General Electric Review*, vol. 41, p. 282, June 1938.			"Selsyn Instruments for Position Systems," by T. M. Linville and J. S. Woodward, *Electrical Engineering*, vol. 53, p. 953, July 1934. "Principles of Selsyn Equipments and Their Operation," by L. F. Holder, *General Electric Review*, vol. 33, p. 500, September 1930. "The Totalizing and Remote Indication of Electric Power and Its Reactive Component," by H. E. Nock and H. S. Edgerly, *General Electric Review*, vol. 27, p. 758, November, 1924. "Telemetering," by C. H. Linder, C. E. Stewart, H. B. Rex, and A. S. Fitzgerald, *Transactions of A. I. E. E.*, vol. 48, p. 766, July 1929.		
(1) (3) (9)	(1) (5) (9) (11)			(1) (9)		

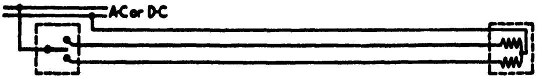
(*e*) May require insulating transformers, lightning arresters or drainage coils in certain cases.
(*f*) Depending on distance.
(*g*) With integrator attachment on recorder.
For numerical references, see *References*, p. 175.

ing of a quantity at a remote point by electrical translating means. Electrical or mechanical quantities are normally involved; although there are other miscellaneous applications for telemetering. In a broad sense, therefore, telemetering includes the remote indication of any quantity, and in the electrical utility industry, perhaps its greatest use is for load dispatching purposes, where an indication of the loads carried by generation and transmission facilities at key points on the system, provides an indication or a graphic record of load conditions. Within the scope of this section, it is possible to include only those methods which pertain to the transmission of kilowatthour, kilovarhour or demand readings.

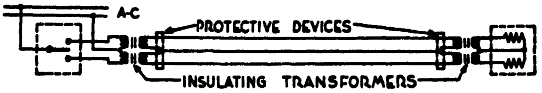
Typical true telemetering systems, adaptable to the transmission of a wide variety of readings, including the indication of kilowatts, kilovars, etc., are covered briefly in Table 6-C, which gives a resumé of the more common methods. In most cases, integrators may be applied to the receiving equipment for indicating kilowatthours and associated quantities. The references listed in the table, and also the numerical references in the text refer to those listed under *References* at the end of this part of this section. They include more detailed descriptions, and examples of applications. References (1) and (9) include also extensive bibliographies and descriptions of principles, and reference (9) includes an extensive table, along



(a) Two-wire operation



(b) Three-wire operation



(c) Three-wire operation with insulating transformers for open and exposed wires

Fig. 6-33. Simplified Diagrams Illustrating Basic Methods of Remote Metering by Direct Operation

the lines of Table 6-C, that covers many additional systems.

Extension of Instrument Transformer Secondaries

Where distances are short, this method is sometimes practical for distances up to several thousand feet. With 5-ampere secondary current transformers it is desirable to use relatively large conductors to keep the current transformer burden as low as possible; current transformers should be tested under the actual burdens, and corrections for their performance should be applied to the watthour meters. Similarly, for potential transformer secondaries, relatively large conductors will reduce the errors that result from potential leads. Potential transformers preferably should be tested as of the metering point by the use of equivalent resistors, or the lead correction should be calculated as described in Section 5 and coordinated with the potential transformer test results. This method may be extended by resorting to the use of meters operating at current values less than the conventional 2.5 or 5 amperes.

Remote Location of Demand Meters

When the sending contact device in the watthour meter is remotely located from the receiving demand meter or totalizing device, remote demand metering is involved. Frequently the problem also includes totalization, either at the sending or receiving end, or both. Totalization has been treated separately and the solution for it generally follows the same lines as that for local totalizing.

Remote demand metering, therefore, embraces suitable methods and channels for the transmitting and receiving of impulses produced at the sending end and recorded at the receiving end.

Direct Operation—There are many cases where it is not necessary to employ special equipment for the transmission of impulses. Fig. 6-33 shows basic methods of remote metering by direct operation. It is possible to allow considerable line resistance in series with the operating coils of the receiving device and still maintain satisfactory operation. This line resistance at the same time reduces the safety factor and if the line includes inductance or capacitance it also imposes an additional burden on the contact device at the sending end.

In Fig. 6-33, the two-wire contact-device principle has been included, although, in general, it should not be used for remote metering. As the distance between sending and receiving points becomes greater, the possibility of external interference increases, making the two-wire principle much more unsatisfactory for remote metering than for local totalization. From a practical point of view, therefore, direct operation necessitates the use of three line wires and materially increases the cost of transmitting channels in comparison with that of the two line wires required for the polarized-relay operation which will be described later.

The operating current of the receiving device determines in a large measure the maximum permissible line resistance. The higher the operating current, the lower the line resistance. An auxiliary relay, Fig. 6-34, with a small operating current of approximately 0.05 amp at 120 volts, 60 cycles may be used to extend the operating range. The contacts of such a relay, in turn control the operation of the demand meter, or one circuit of a totalizing relay. The indicated distances and resistances in Table 6-D are based on the use of such an auxiliary relay and presuppose that the line has no appreciable inductance or capacitance, and that it is free from external magnetic interference.

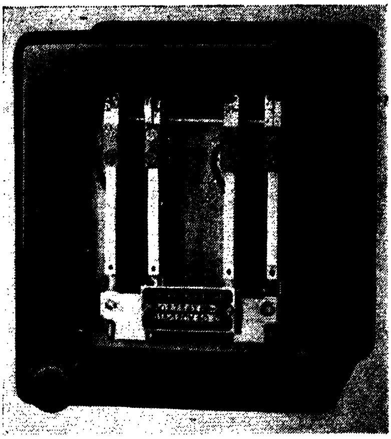


Fig. 6-34. Type S-1 Auxiliary Relay (General Electric Co.)

When open and exposed wires are used, it is often necessary to employ

TABLE 6-D

MAXIMUM LINE RESISTANCES AND DISTANCES FOR REMOTE METERING WITH AUXILIARY RELAY

Fig.	Operation	Max. Line Resistance Per Wire	Distance Using No. 19 Wire	Distance Using No. 6 Wire
		120-volt Alternating Current		
6-33(a)	2-wire	800 ohms	20 miles	....
6-33(b)	3-wire	800 ohms	20 miles	....
6-33(c)	3-wire, with Insulating Transformers	400 ohms	....	See note

Note: With No. 6 wire the distance will not be limited by the maximum resistance but by the comparative cost of three conductors against two conductors for polarized relay operation.

The maximum line resistances per wire are based on the use of sensitive receiving devices.

The maximum distances are based on the assumption that all conductors are copper wires.

insulating transformers. These materially reduce the maximum permissible line resistance, but because of larger cross sections of open wire than are found in telephone cable, the maximum permissible distance is considerable.

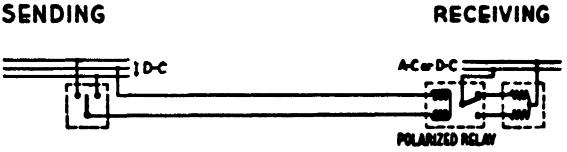
Differential Totalization — Demands from widely divergent points may be combined on a single two-wire channel, either directly or differentially, by thermal converters or thermal transmitters on each circuit, and measured with a potentiometer recorder at the receiving end. This method is described under *Local Totalization.*

When remote metering includes differential totalization and the transmission of impulses, it is normally necessary to use two transmitting channels, one for *additive* impulses and one for *subtractive* impulses. However, conditions are encountered where the sending equipment can be so arranged as to require the use of only one transmitting channel.

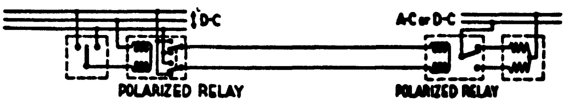
When two channels are used, the receiving device may be assumed to have a zero-center scale. Minus impulses will move the pointer to the left and plus impulses will move it to the right. When the total power is zero, no impulses are transmitted and the pointer is at zero on the center of the scale.

If the sending device is so arranged that for zero power a constant rate of impulses is produced and transmitted, and if the pointer of the receiving device is arranged to move from left to right, the constant rate of impulses can be so chosen that for zero power the pointer will again be at the center of the scale. At the sending end, minus impulses can be subtracted from the constant-rate impulses and plus impulses added to the constant-rate impulses. Thus only one transmitting channel will be required.

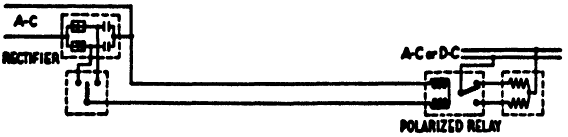
There are limitations to combining at the sending end a constant rate of impulses with intermittently and irregularly time-spaced plus and minus impulses. One solution is to use a totalizing watthour meter with meter elements so constructed and arranged that the combining is accomplished in terms of torques exerted on the meter shaft. This has the advantage of eliminating errors from backlash in gear trains. The meter, however, must be



(a) Half-voltage operation with d-c source



(b) Full-voltage operation with d-c source



(c) Half-voltage operation with copper-oxide rectifier

Fig. 6-35. Simplified Diagrams Illustrating Basic Methods of Remote Metering by Polarized Relays

TABLE 6-E
MAXIMUM TOTAL LINE RESISTANCES PER LOOP AND DISTANCES FOR REMOTE METERING BY POLARIZED-RELAY OPERATION

Fig.	Operation	Max. Line Resistance Total	Distance Using No. 19 Wire	Max. Line Resistance Total	Distance Using No. 19 Wire
		120-volt Direct Current		240-volt Direct Current	
6–35(a)	Half-voltage operation	175 ohms	2 miles	2200 ohms	25 miles
6–35(b)	Full-voltage operation	2600 ohms	30 miles	6800 ohms	80 miles
		Copper-oxide Rectifier—Double voltage Connections			
6–35(c)	Half-voltage operation	900 ohms	10 miles		

The maximum distances are based on the assumption that all conductors are copper wires, and that the wires are free from inductance, capacitance, and external magnetic interference.

of special design and as a result is not so easy to test and maintain as standard watthour meters.

The receiving device may be a standard impulse-operated demand meter, but with the obvious disadvantage that the number of impulses corresponding to full scale for plus or minus demand is reduced. The point on the scale corresponding to zero demand need not be at the center. The constant rate of impulses can, at least theoretically, be so chosen as to be equal to the maximum anticipated minus demand.

Polarized-Relay Operation — This method, as shown in Fig. 6-35, is advantageous in that it requires but two wires, although it is equivalent to three-wire contact-device operation. However, being polarized, it is necessary to provide a three-wire d-c source at the sending end. A two-wire d-c source can also be used by establishing a center point through the use of a resistance with a center tap connected across the source.

The polarized relay which is employed is a d-c two-position relay with no neutral position. Such a relay is shown in Fig. 6-36. The relay armature takes one position for a positive impulse and the opposite position for a negative impulse (when the potential applied to the relay winding is reversed). Therefore, it responds only to the impulses of alternate polarity as produced by the two sides of the three-wire contact device at the sending end. The oscillations of the relay armature causes two sets of three-wire contacts to close, either on one side or on the other, and these contacts control either a demand meter or one circuit of a totalizing relay.

The three-wire contact device at the sending end is connected directly to the d-c source. It is standard practice to employ protective resistors in series with the leads to the contact device to limit the current in case of an accidental short circuit.

The polarized operation may function on the basis of half of the d-c source voltage, or the full d-c source voltage.

In the first instance, Fig. 6-35(a), the voltage of the transmitted impulse is one-half of the source voltage, and alternate impulses have alternate polarity. Thus the first impulse may have plus-to-neutral voltage, and the next following impulse have minus-to-neutral voltage.

With full-voltage operation, Fig. 6-35 (b), each impulse has the full volt-

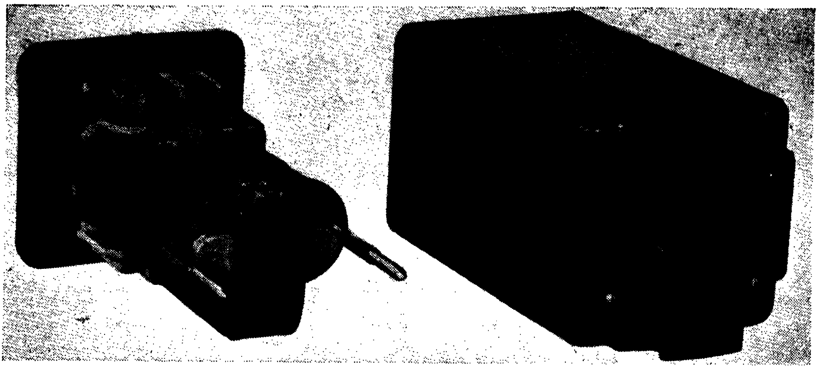


Fig. 6-36. Polarized Two-position d-c relay for Remote Metering, cover shown at right

age of the d-c source, with successive impulses having opposite polarity. This method obviously increases the distance over which the impulse can be transmitted, but at the same time necessitates an additional polarized relay at the sending end.

Rectifiers—Where a suitable d-c source is not available at the sending end, a selenium or a copper oxide rectifier can be used, Fig. 6-37. It may be connected internally, either for double voltage or as a bridge, as is shown in Fig. 6-38(a) and 6-38(b).

The double-voltage-connected rectifier gives only half-wave rectification and its regulation is, therefore, not comparable to full-wave rectification such as that obtained from a bridge-connected rectifier. It has, however, the distinct advantage of providing a sufficiently high d-c voltage to operate the polarized relay from the line-to-neutral voltage. To assure satisfactory regulation for remote metering, the d-c load should consist of only one polarized relay.

As it provides full-wave rectification, the bridge-connected rectifier has better regulation. However, because of the internal voltage drop, a 120-volt a-c input will give an rms d-c voltage of approximately 110 volts. This is a distinct disadvantage, as a polarized relay to be operated from line-to-neutral requires a higher line-to-line voltage than 110. One practical solution is to use two rectifiers and connect them on the d-c side as two d-c generators for a three-wire d-c system. This will necessitate isolating the a-c inputs by means of an insulating transformer.

The full-load volt-ampere burden of the double-voltage-connected rectifier shown in Fig. 6-37 is low enough to allow operation from potential transformers. The rectifier will heat up on over-voltage and should therefore be fused with two-ampere fuses and protected by means of a suitable over-voltage arrester.

Line Resistance—The maximum permissible distances given in Table 6-E presuppose that the line has no appreciable inductance or capacitance and that it is free from external magnetic interference. If open line wires are used and if these are exposed and require the use of insulating transformers, the permissible resistance of the wires is materially reduced from that which can be allowed for wires in a telephone cable.

The problem of sending polarized d-c impulses through insulating transformers is two-fold. First, the magnitude of the impulse depends not on the constant-current value but on the rate of change in the current. The impulse, therefore, does not last for the duration of the closing of the contact device at the sending end but is present only for a moment as the contact device closes. Second, the impulse cannot be transferred from the primary to the secondary of the insulating transformer without a very appreciable decrease in its value. The value of the impulse at the receiving end is only a fraction of what it is at the sending end.

Transmitting Channels—*Wire Channels*—A pair of wires in a cable constitutes an ideal channel for remote metering purposes. It may be a leased pair from a communication company, or it may be a pair in a privately owned cable. Such a channel offers the advantage that it is practically unaffected by external conditions and therefore assures that the impulses will be transmitted from the sending to the receiving end without interference.

If at all possible, the transmitting channel should be used for no other purposes than for remote metering. Use of the channel for some other function, such as telephoning, is usually not practical as it will require high-frequency calling equipment for the telephone installation as well as filters for the demand-metering equipment, a combination which is costly. Furthermore, it may be difficult to obtain a leased pair of wires to be used for more than one purpose.

The use of leased circuits with ground return will sometimes mean a cost lower than that for a channel consisting of two metallic conductors. Ground-return circuits are commonly used for such applications as teletyping. However, circuits for remote metering are expected to provide a higher degree of reliability and freedom from interference than in the case of a teletype circuit. For the latter an occasional garbling of words will normally not be serious, as the words can usually be deciphered. This does not apply to a circuit for remote metering where an error in transmission of impulses cannot readily be detected and compensated. Therefore, ground-return circuits should be avoided when reliable operation is a primary consideration.

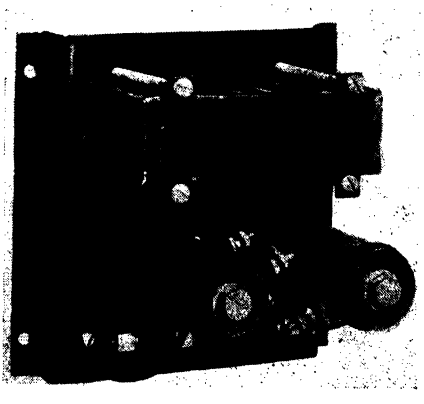


Fig. 6-37. Copper Oxide Rectifier for Remote Metering, with cover removed

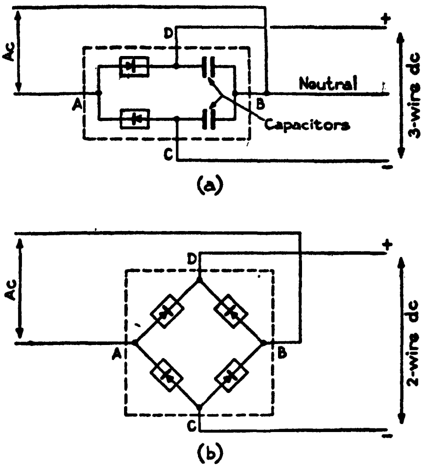


Fig. 6-38. Simplified Connection Diagrams for Copper Oxide Rectifier
(a) Double-voltage Connections
(b) Bridge Connections

Protective Equipment—If the channel employed consists of open wires, it is subject to external disturbances and should be provided with protective equipment. From the standpoint of protection, open channel wires are usually classified as:

Class 1: Wires which do not cross or parallel power lines.
Class 2: Wires which cross but do not parallel power lines.
Class 3: Wires which parallel power lines but are not on the same poles

or towers and do not cross power lines.

Class 4: Wires which are on the towers or poles with the power lines.

The protective equipment shown in Fig. 6-39 is designed for Class 4 protection. For Class 3 the double-pole horn gaps can be omitted. For Class 2, both the horn gaps and the drainage coils can be omitted. For Class 1 it is sufficient to use only the vacuum gaps.

As long as the channel wires do not have high voltages induced in them (Classes 1 and 2) and therefore do not require insulating transformers, the problem of transmitting polarized d-c impulses is relatively simple. Where insulating transformers are required, it is still possible to transmit polarized impulses but the problem is much more difficult, as already stated in the paragraph devoted to *Line Resistance.*

Carrier-Current Channels — Carrier-current channels frequently offer an economical substitute for wire-line channels used for telephony, supervisory control, automatic operation of apparatus, etc. When carrier equipment is used for other purposes, such as telephony or supervisory control, simultaneous use of the channel for remote metering can often be arranged at slight additional cost. The equipment can be coupled either to overhead transmission lines or to existing open-wire telephone lines.

The low cost of a carrier channel over appreciable distances makes it of unusual interest where the remote metering is for guidance of a load dispatcher, and under such conditions should always be considered as an alternative to the use of wire circuits.

When maximum accuracy of remote metering is required over a carrier-current channel, the use of two separate audio frequencies (tones) is preferable, for the same reason that three-wire operation is preferable to two-wire operation. However, if first cost is the determining factor, it is sometimes possible to make a substantial reduction in the cost of the carrier-current equipment by using impulses of only one audio frequency, or by using impulses of unmodulated carrier frequency. The scheme selected will depend on how many other purposes the carrier channel will serve, and on the metering accuracy requirements.

When billing is involved, the reliability of the channel is of prime importance. A pair of telephone wires in cable has the advantage of simplicity. A carrier channel over a power line with the necessary auxiliary relays will usually have the same reliability. When operators are available at the receiving point, most carrier channels can be arranged to provide an indication of channel or equipment failure, a feature often impractical with wire lines.

With remote metering over a carrier channel, it is necessary only to interpose a polarized auxiliary relay, Fig. 6-36, between the carrier-current transmitter and the contact device at the sending end. No auxiliary relays

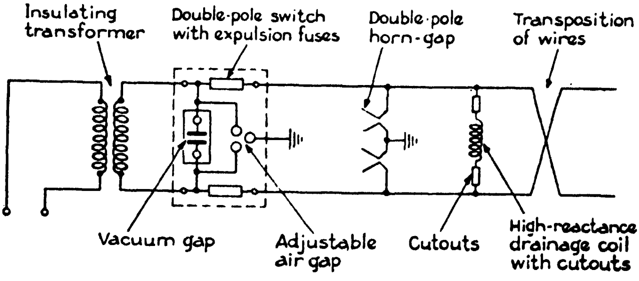


Fig. 6-39. Diagram of Connections for Protective Equipment for Open-Channel Wire on Same Poles with Power Lines

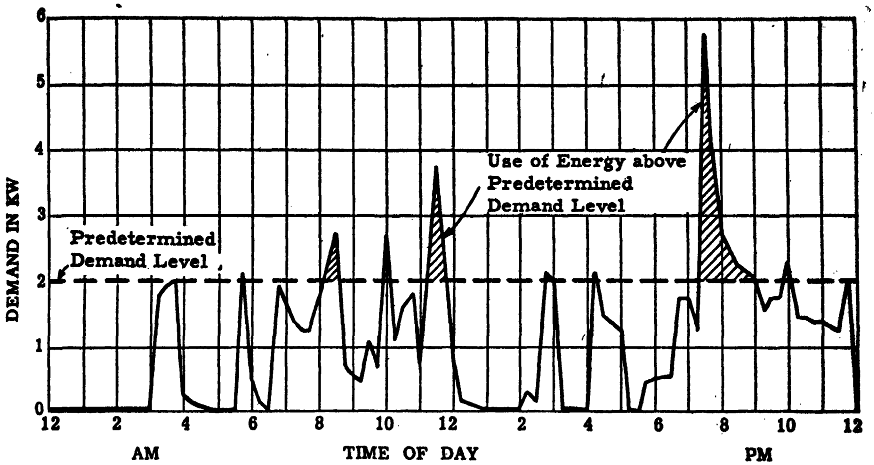


Fig. 6-40. Application of Demand Level to a Typical Daily Load Curve

are necessary at the receiver end, other than those which form an integral part of the carrier-current receiver equipment. The latter relay contacts are adequate to handle a demand meter or one circuit of a totalizing relay.

References

(1) Borden, Perry A. and Thynell, Gustave M. — *Principles and Methods of Telemetering*. Reinhold Publishing Company, 1948.
(2) Brown, E. H.—*Power Telemetered on Pennsylvania Line*. Electrical World, February 29, 1936.
(3) Bristol Company, The.—*Metameter System of Telemetering*.
(4) Burnham, W. H.—*New Devices Derived from a Torque Balance Telemeter*. AIEE Transactions, Volume 67, 1948, part 1, page 307.
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(6) Leeds and Northrup Company—*Micromax Telemetering and Totalizing Recorders for Electric Power*.
(7) Lincoln, P. M.—*Totalizing of Electric System Loads*. AIEE Transactions, Volume 48, 1929, page 775.
(8) Lunge, G. S.—*Why Telemetering*. General Electric Review, Volume 42, 1939, page 150.
(9) Report of AIEE Subcommittee on Telemetering and Joint Committee on Telemetering and Supervisory Control—*Telemetering, Supervisory Control, and Associated Circuits*. AIEE Transactions, 1941, Volume 60, page 1411.
(10) Sangamo Electric Company—*Demand Totalizing with Thermal Demand Transmitters*.
(11) Westinghouse Electric Corporation—*High-Rate Impulse Telemetering, Power Line Carrier Equipment*.
(12) Manufacturers' Bulletins.

KILOWATTHOUR MEASUREMENT ABOVE PREDETERMINED DEMAND LEVELS

For load studies, rate studies, or other special applications, a differential register is available which will register the total kilowatthours as well as the number of kilowatthours consumed when the demand is in excess of a predetermined kilowatt demand level. This is accomplished with a differential gear, one side of which is driven at a speed proportional to a given kilowatt load by a synchronous motor, and the other side from the watthour meter disk. A ratchet prevents reverse rotation when the speed of the meter driven gear is less than that of the motor driven gear. The result is a reading

on one set of dials of the total kilowatthours, and on another set of dials of the kilowatthours used when the demand is greater than the established level. Differential registers with as many as three differentials are also made, permitting measurement on separate dials of the kilowatthours used when demands exceed three different predetermined demand levels. The application of this device is illustrated for an actual load curve in Fig. 6-40. The shaded area, indicated above the horizontal dashed line, represents energy used at a high demand level.

References

Sangamo Electric Company—*Differential Registers.* Bulletin 345.

SECTION 7

METER WIRING DIAGRAMS

SYMBOLS FOR METERING DIAGRAMS

The symbols used in the metering diagrams conform to ASA Standard Z 32.3-1946, *Graphical Symbols for Electric Power and Control.*

METER CONNECTION DIAGRAMS

The diagrams in Figs. 7-8 to 7-38, inclusive, cover the wiring connections for accepted methods of metering a-c circuits. These diagrams are applicable to the measurement of both power and energy, and the outlines may, therefore, be assumed to represent either watthour meters or wattmeters.

Phase Sequence and Identification

Any phase sequence or any arbitrary numerical or letter scheme of phase identification may be adopted. However, in these diagrams, the phase sequence is assumed to be 1-2-3 counterclockwise in the case of three-phase circuits, and in two-phase circuits, phase *A* is assumed to be leading phase *B* by 90 degrees, counterclockwise.

Watthour meters and wattmeters for measuring watthours and watts can be correctly connected without knowledge or consideration of the actual phase sequence. However, when these devices are used for measuring the reactive component of power (vars) or of energy (varhours), the phase sequence must be known and be taken into consideration. In three-phase circuits where the arbitrary phase identification adopted is such that the phase sequence is 3-2-1, or where on two-phase circuits phase *B* leads phase *A* by 90 degrees, the line and load connections to each potential coil of the reactive meter should be interchanged. See Figs. 7-29 to 7-37. For instance, in Fig. 7-29, for 3-2-1 phase sequence the connections to the reactive meter would be 5-4 (line-load) on the top element as shown, and 7-6 (line-load) on the bottom element. Also in three-phase, four-wire delta circuits the designation of phases in relation to the grounded point must be taken into consideration as is illustrated in the difference between Figs. 7-39 or 7-40 and Figs. 7-30 or 7-31.

Phase Shifting Methods and Devices

The phase displacement required for measurement of the reactive component of power or energy is usually accomplished by means of phase-shifting transformers, Figs. 7-29 to 7-35, although it may be obtained by other methods as illustrated in Figs. 7-28, 7-36 and 7-37.

Specification MS-6, *Marking and Arrangement of Terminals for Phase-Shifting Devices Used in Metering,* published by EEI, includes standardized terminal markings for phase-shifting devices for specific types of services, Fig. 7-39, standardized terminal markings for a universal phase-shifting device on common types of services, Fig. 7-40, and standardized terminal arrangements for phase-shifting devices, Fig. 7-41.

Figs. 7-39 and 7-40 do not indicate relative positions of the meter elements, but show relative potential connections to the elements. For example, using a three-phase three-wire delta type of service, if service phases 1, 2 and 3 with counterclockwise rotation are connected to terminals ①, ② and ③ respectively on the phase-shifting device, then a meter potential element which would be connected from phases 1 to 2 to measure kwhr should be connected from terminals ④ to ⑤ of the phase-shifting device to measure kvarhr or kvahr.

Power Factor

For convenience, the diagrams in this section show the power factor of the load as lagging in all cases involving reactive or kva metering.

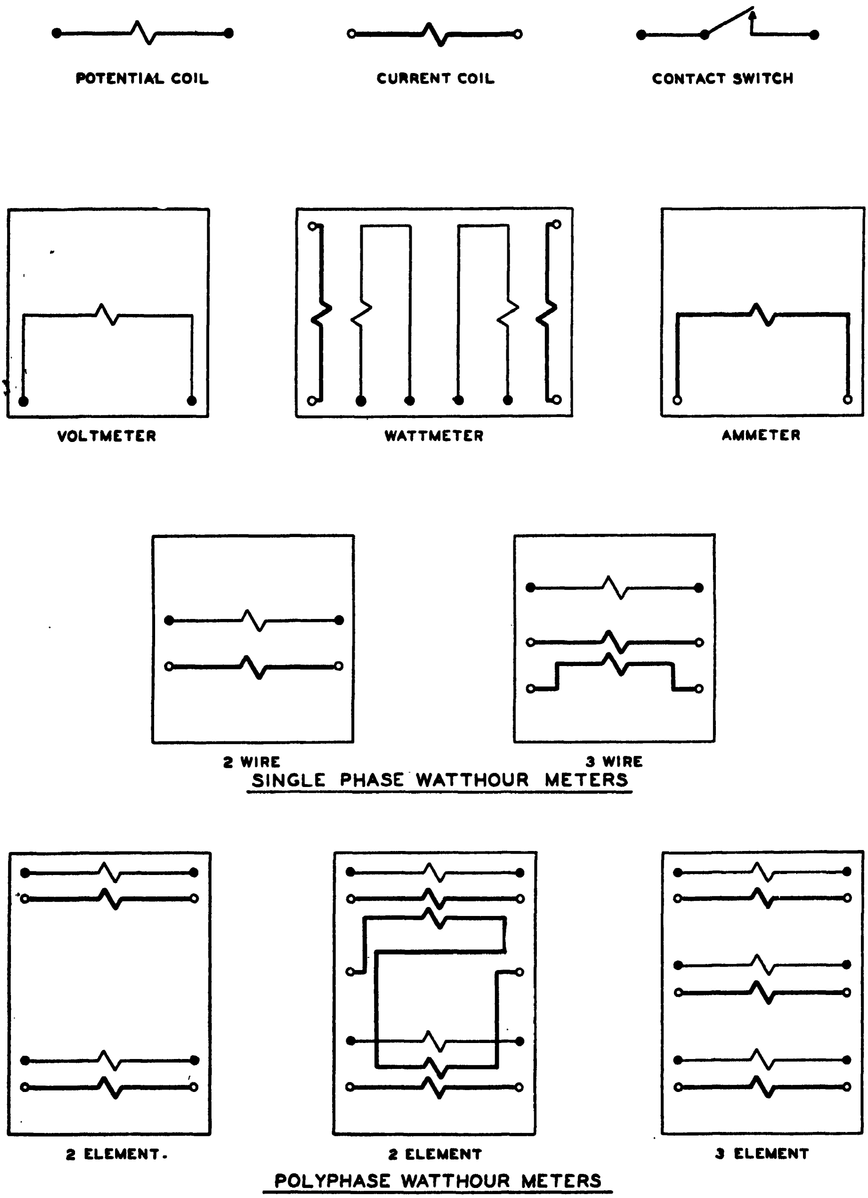
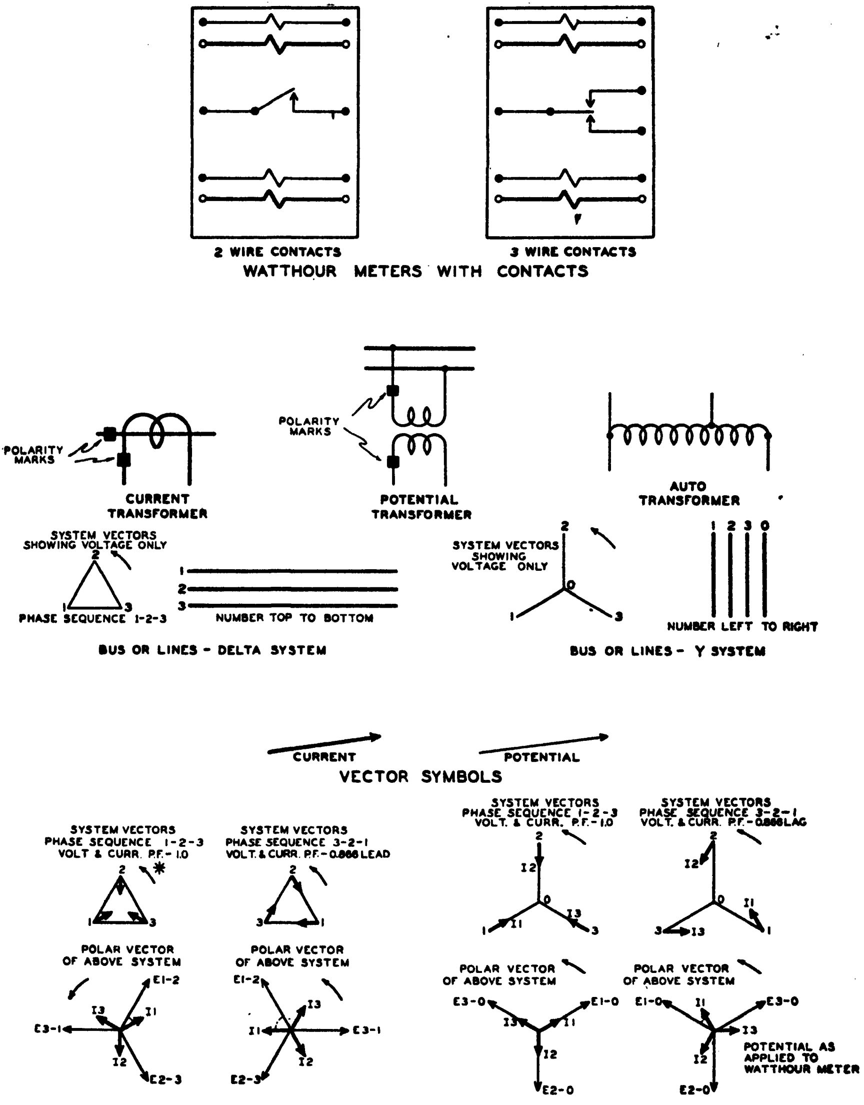
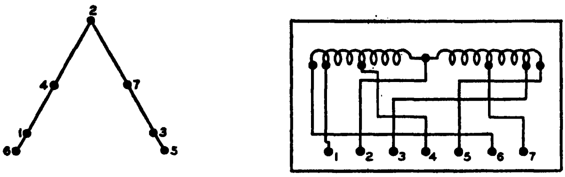


Fig. 7-1. Symbols for Metering Diagrams

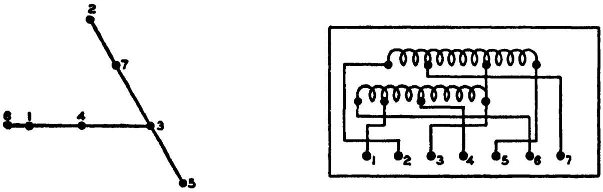

2 WIRE CONTACTS
3 WIRE CONTACTS
WATTHOUR METERS WITH CONTACTS
POLARITY MARKS
CURRENT TRANSFORMER
POLARITY MARKS
POTENTIAL TRANSFORMER
AUTO TRANSFORMER
SYSTEM VECTORS SHOWING VOLTAGE ONLY
2
1
3
PHASE SEQUENCE 1-2-3
1
2
3
NUMBER TOP TO BOTTOM
BUS OR LINES - DELTA SYSTEM
SYSTEM VECTORS SHOWING VOLTAGE ONLY
2
0
1
3
1 2 3 0
NUMBER LEFT TO RIGHT
BUS OR LINES - Y SYSTEM
CURRENT
POTENTIAL
VECTOR SYMBOLS
SYSTEM VECTORS PHASE SEQUENCE 1-2-3 VOLT & CURR. P.F.-1.0
2 *
1
3
SYSTEM VECTORS PHASE SEQUENCE 3-2-1 VOLT. & CURR. P.F.-0.866 LEAD
2
3
1
SYSTEM VECTORS PHASE SEQUENCE 1-2-3 VOLT. & CURR. P.F.-1.0
2
I2
0
1
I1
I3
3
SYSTEM VECTORS PHASE SEQUENCE 3-2-1 VOLT. & CURR. P.F.-0.866 LAG
2
I2
0
I1
3
I3
1
POLAR VECTOR OF ABOVE SYSTEM
E1-2
I3
I1
E3-1
I2
E2-3
POLAR VECTOR OF ABOVE SYSTEM
E1-2
I3
I1
E3-1
E2-3
I2
POLAR VECTOR OF ABOVE SYSTEM
E3-0
E1-0
I3
I1
I2
E2-0
POLAR VECTOR OF ABOVE SYSTEM
E1-0
I1
E3-0
I3
I2
E2-0
POTENTIAL AS APPLIED TO WATTHOUR METER

* VECTOR SEQUENCE COUNTER CLOCKWISE; ASSUMED AS SUCH WHEN NOT MARKED.

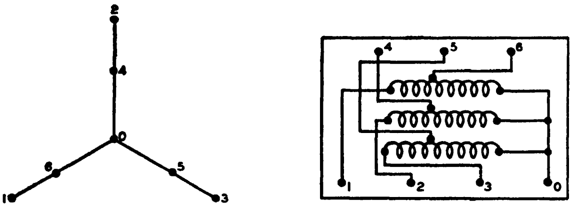
Fig. 7-2. Symbols for Metering Diagrams



3 PHASE 3 WIRE

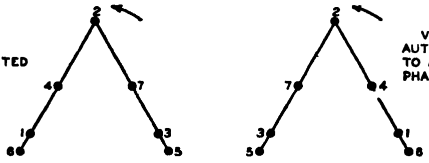


3 PHASE 3 WIRE



3 PHASE 4 WIRE WYE

VECTOR DIAGRAM OF ONE TYPE OF 3 PHASE 3 WIRE AUTO TRANSFORMER CONNECTED TO A SYSTEM HAVING 1-2-3 PHASE SEQUENCE.



VECTOR DIAGRAM OF SAME AUTO TRANSFORMER CONNECTED TO A SYSTEM HAVING 3-2-1 PHASE SEQUENCE.

COMPARISON OF VECTOR DIAGRAMS OF AUTO TRANSFORMER 1-2-3 AND 3-2-1 PHASE SEQUENCE

Fig. 7-3. Examples of Autotransformers for Kvarhr Metering

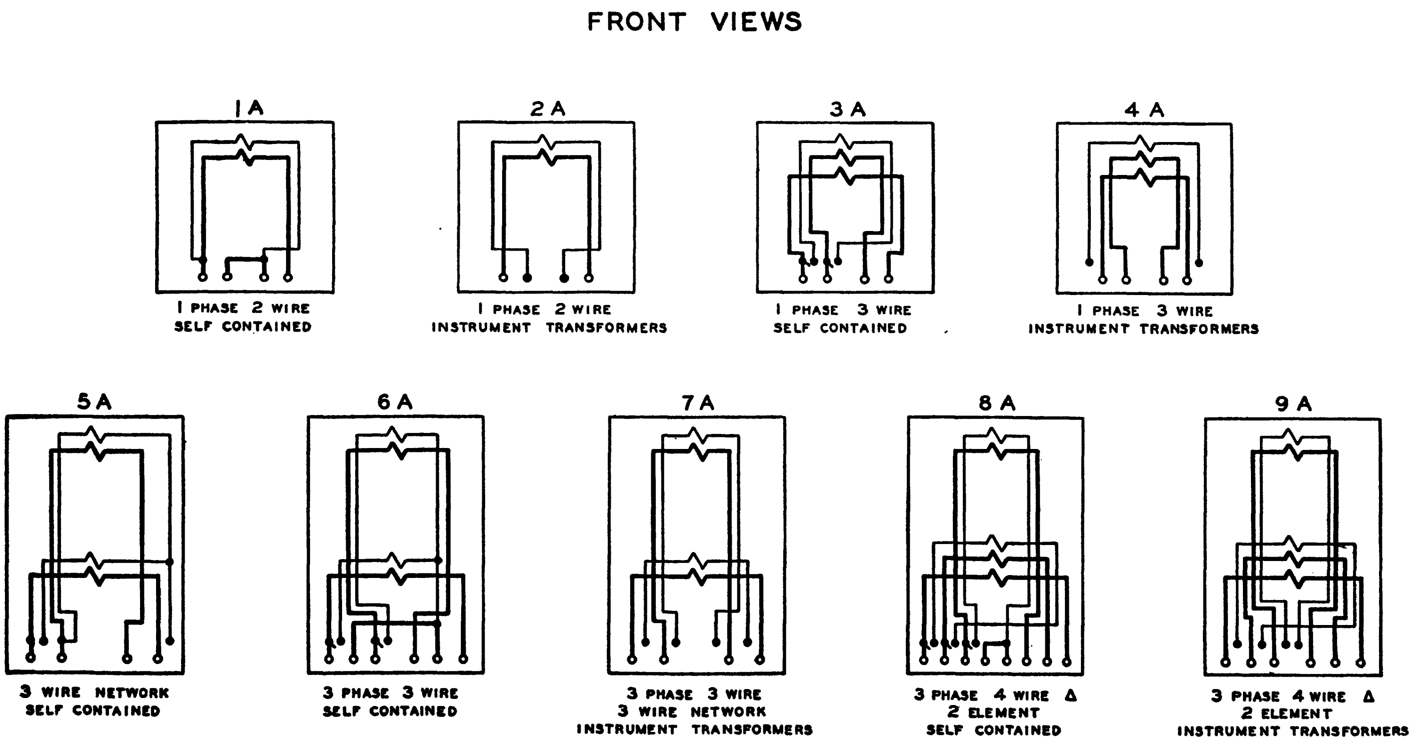


Fig. 7-4. Terminal Connections of Type "A" (Bottom connected) Meters

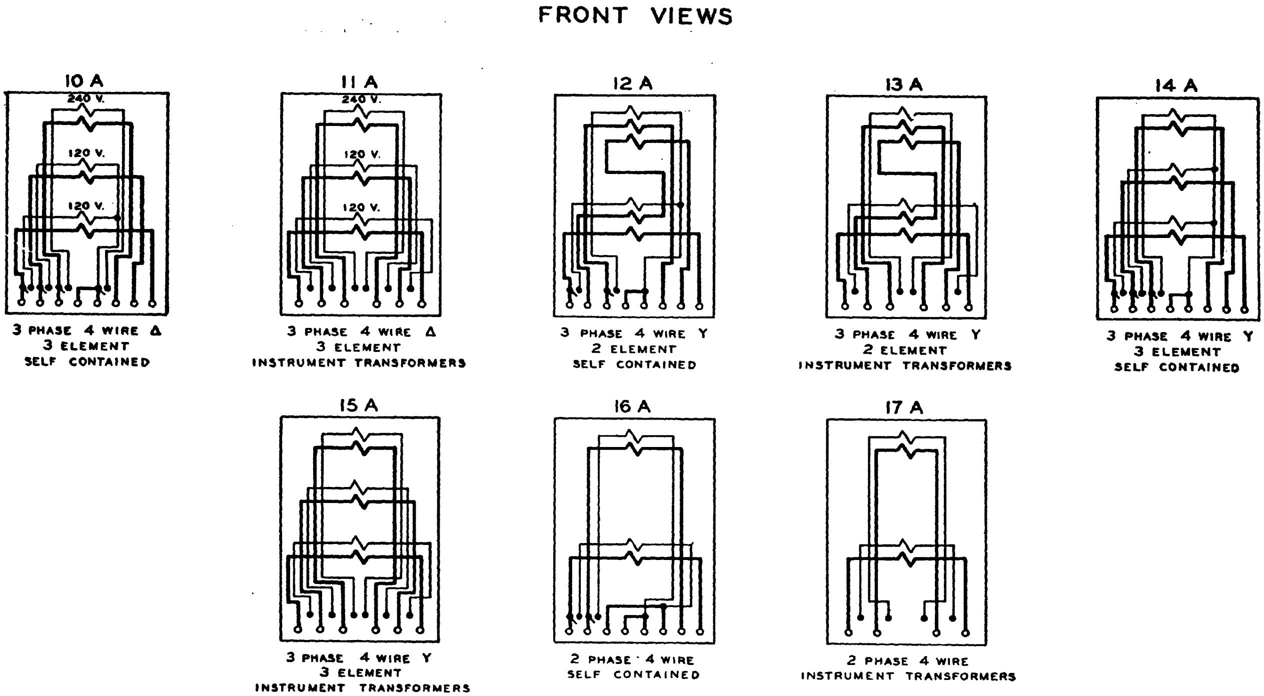


Fig. 7-5. Terminal Connections of Type "A" (Bottom connected) Meters

FRONT VIEWS

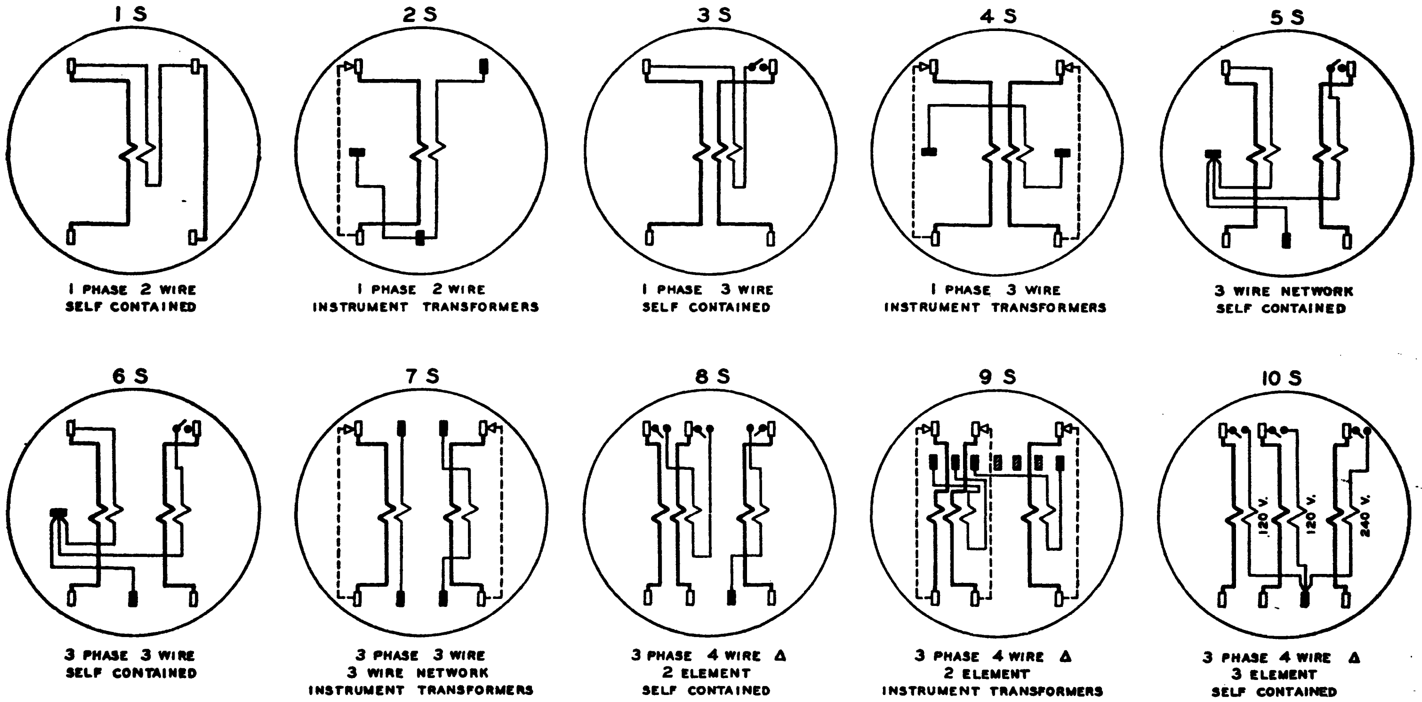
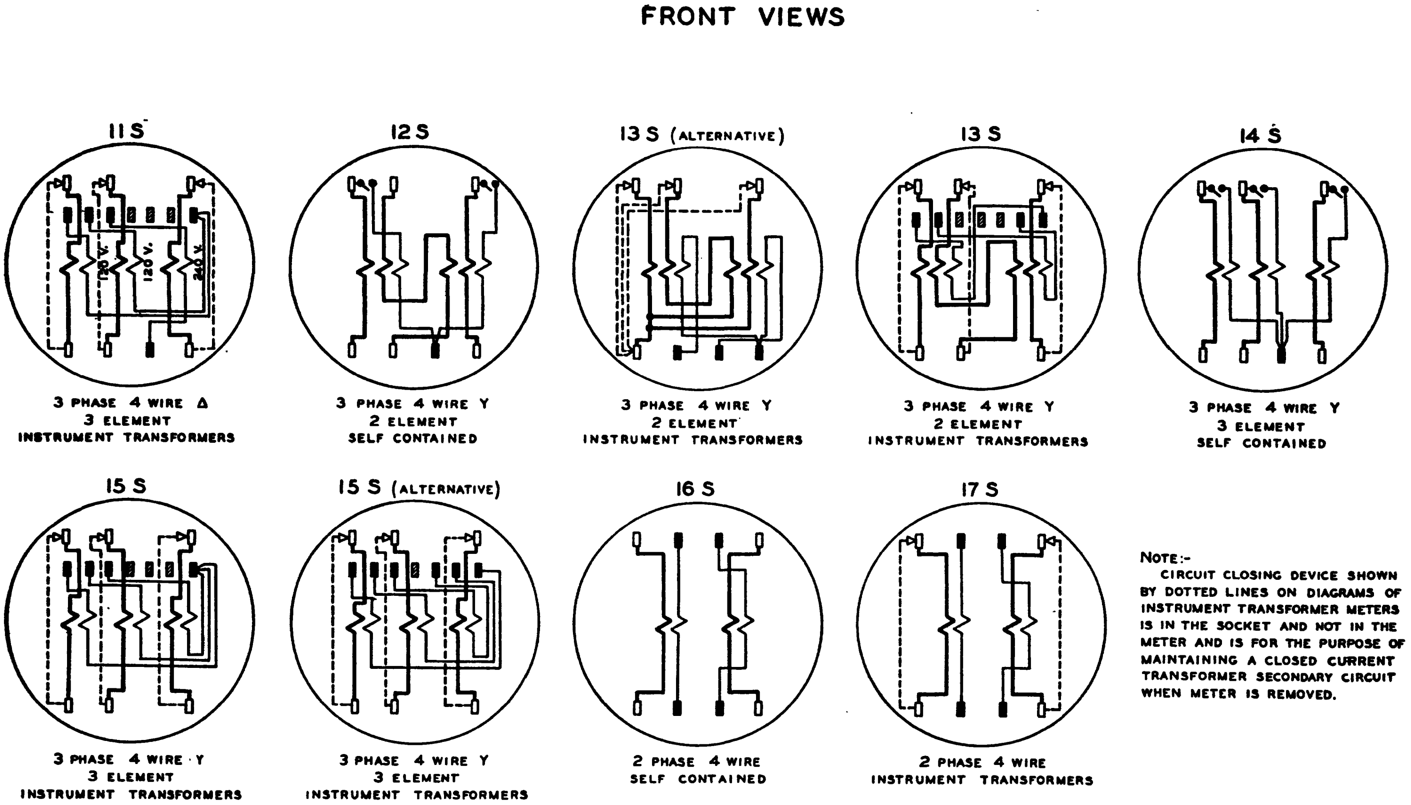


Fig. 7-6. Terminal Connections of Type "S" (Socket) Meters



NOTE:-
CIRCUIT CLOSING DEVICE SHOWN BY DOTTED LINES ON DIAGRAMS OF INSTRUMENT TRANSFORMER METERS IS IN THE SOCKET AND NOT IN THE METER AND IS FOR THE PURPOSE OF MAINTAINING A CLOSED CURRENT TRANSFORMER SECONDARY CIRCUIT WHEN METER IS REMOVED.

Fig. 7-7. Terminal Connections of Type "S" (Socket) Meters

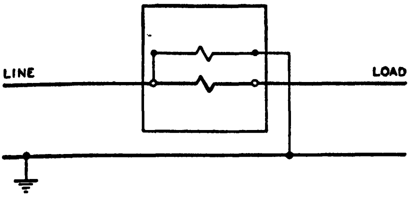


Fig. 7-8. Measurement of Energy in a 2-Wire, A-C Circuit with One Wire Grounded

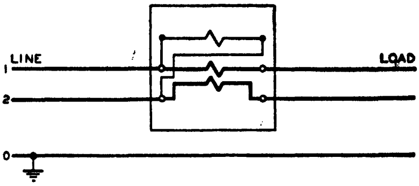
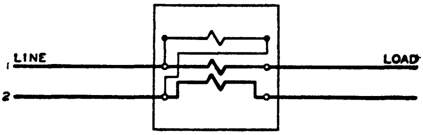


Fig. 7-9. Measurement of Energy in a 3-Wire, Single-phase, A-C Circuit by Means of a 3-Wire Meter

Fig. 7-10. (*right*) Measurement of Energy in an Ungrounded, 2-Wire, A-C Circuit by Means of a 2-Current Coil, 3-Wire, Single-phase, Meter

Note: This method has an application in metering a load taken from the two ungrounded wires of a single-phase, 3-Wire source.



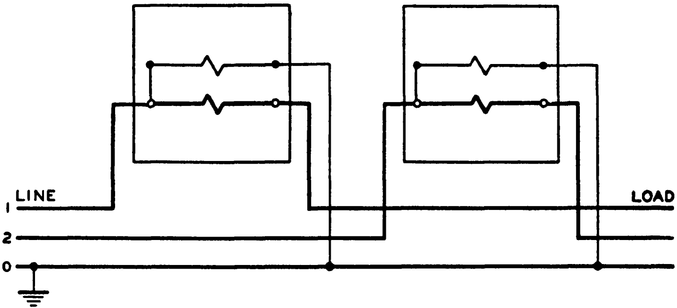


Fig. 7-11. Measurement of Energy in a 3-Wire, Single-phase, A-C Circuit with Two 2-Wire Meters

Note: A 2-Element or one 3-Wire, Single-phase Meter is generally used.

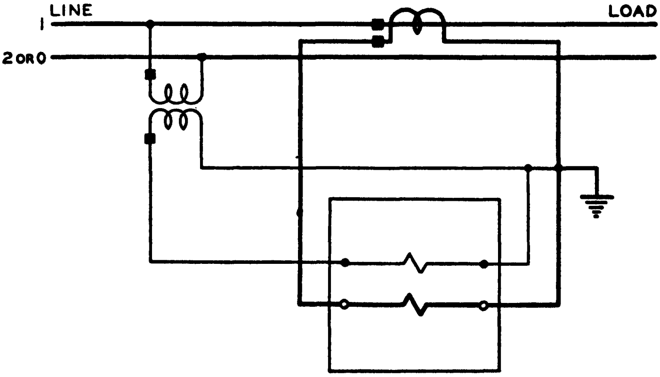


Fig. 7-12. Measurement of Energy in a 2-Wire, Single-phase Circuit Using Instrument Transformers

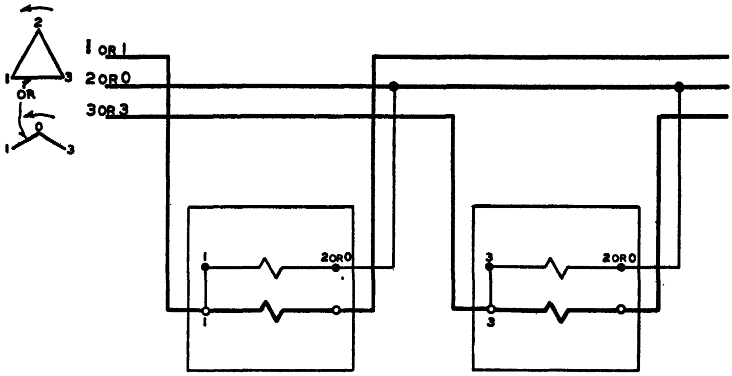


Fig. 7-13. Measurement of Energy in a 3-Wire, 3-Phase Circuit or 3-Wire Circuit from a 4-Wire System Using Two Single-phase Meters

In metering a 3-phase, 3-wire circuit, the two current coils may be connected in any two phase wires; the load side of the potential coils should always be connected to the phase wire not containing a current coil. Should one corner of the delta be grounded it is necessary that the current coils be connected in the ungrounded phase wires. In metering a 3-wire network circuit (one composed of two phase wires and the neutral of a 4-wire wye system) the current coils should always be placed in the two phase wires (not the neutral). It is usual practice to use one 2-element meter, see Fig. 7-14.

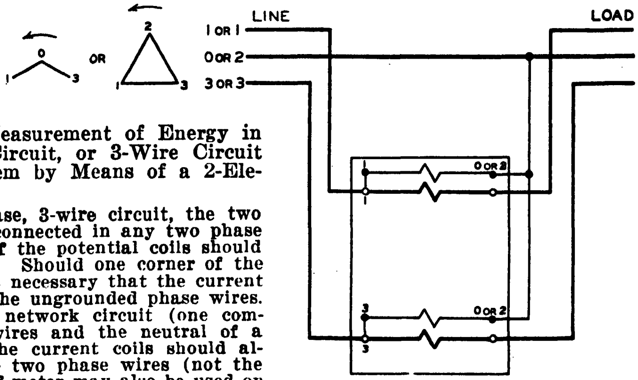
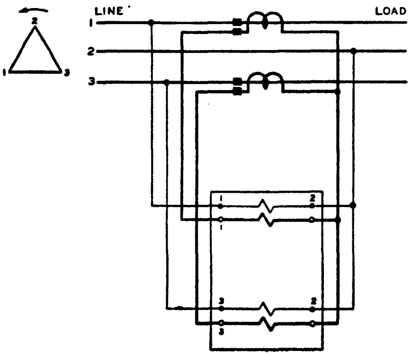


Fig. 7-14. (*right*) Measurement of Energy in a 3-Wire, 3-Phase Circuit, or 3-Wire Circuit from a 4-Wire System by Means of a 2-Element Meter

In metering a 3-phase, 3-wire circuit, the two current coils may be connected in any two phase wires; the load side of the potential coils should taining a current coil. Should one corner of the delta be grounded it is necessary that the current coils be connected to the ungrounded phase wires. In metering a 3-wire network circuit (one composed of two phase wires and the neutral of a 4-wire wye system) the current coils should always be placed in the two phase wires (not the neutral). This type of meter may also be used on a 3-wire, single-phase circuit in which case the grounded neutral wire is used as the common load side potential coil connection.

Fig. 7-15. (*below*) Measurement of Energy in a 3-Phase, 3-Wire Circuit Using a 2-Element Meter with Current Transformers



This diagram is also applicable for metering a 3-wire, single-phase and a 3-wire, open wye (two phase wires and a neutral of a 4-wire wye system) circuit in which case the neutral or ground wire is used as the common load side potential connection only. In metering a 3-phase, 3-wire circuit, the two current coils may be connected in any two phase wires; the load side of the potential coils should always be connected to the phase wire not containing a current coil. Should one corner of the delta be grounded it is necessary that the current coils be connected to the ungrounded phase wires. In metering a 3-wire network circuit (one composed of two phase wires and the neutral of a 4-wire wye system) the current coils should always be placed in the two phase wires (not the neutral).

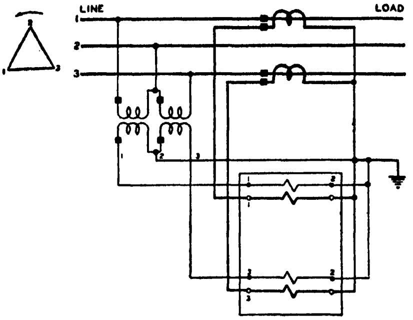


Fig. 7-16. Measurement of Energy in a 3-Phase, 3-Wire Circuit Using a 2-Element Meter with Current and Potential Transformers

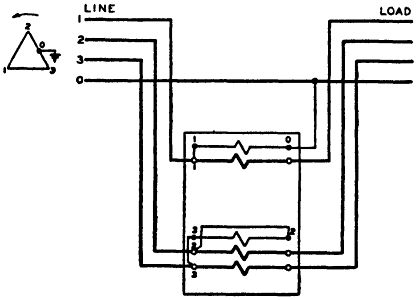
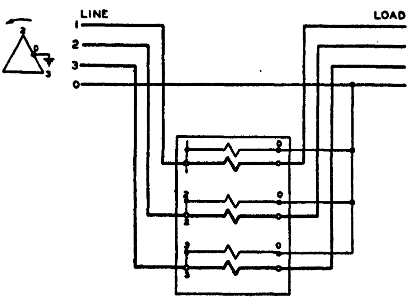


Fig. 7-17. Measurement of Energy in a 3-Phase, 4-Wire, Delta Circuit Using a 2-Element Meter, Having One 2-Wire and One 3-Wire Element

The connections of the phase wires to the elements may differ from that shown above depending on the phase from which the lighting load is taken. The two phase wires from which the lighting load is taken should always be connected to the 3-wire element. For example, if the lighting load was taken from phase 1-2, current 3 should pass through the 2-wire element and currents 1 and 2 should pass through the 3-wire element.



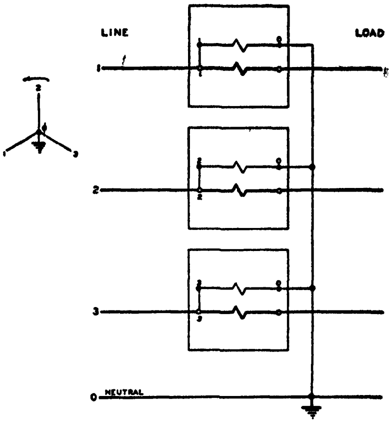


Fig. 7-19. Measurement of Energy in a 3-Phase, 4-Wire, Wye Circuit Using Three Single-phase Meters

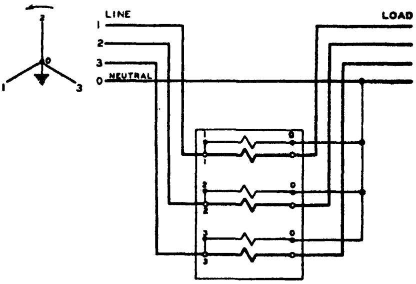


Fig. 7-20. Measurement of Energy in a 3-Phase, 4-Wire, Wye Circuit Using a 3-Element Meter

Fig. 7-18. (*left*) Measurement of Energy in a 3-Phase, 4-Wire Delta Circuit With a 3-Element Delta Meter

This meter has two elements operating at half line to line voltage and one element at 86% of line to line voltage. One practical method for metering a 240-volt, 4-wire delta system is to use a meter having one 240-volt element and two 120-volt elements, the former having half the current rating of the latter. The phase wires from which the lighting load is taken must be connected to the two elements having the lower voltage rating. A standard 3-element, 240-volt meter (all elements the same) may be used, working two elements at half rated voltage. In connecting this standard meter for metering a 3-phase, 4-wire, delta load, the phase wires supplying the lighting load may be connected to any element.

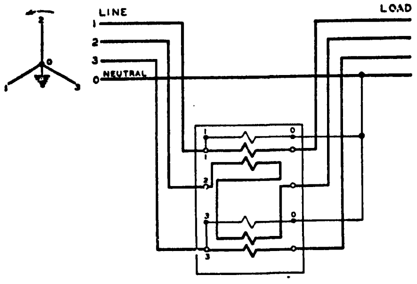


Fig. 7-21. (*left*) Measurement of Energy in a 3-Phase, 4-Wire, Wye Circuit Using a 2-Element, 4-Wire, Split Coil Meter

This meter may be used in place of the 3-element meter shown in Fig. 7-20. Its accuracy is based on the assumption that the negative vectorial sum of the two phase voltages equals the third phase voltage. Where the phase voltages are considerably unbalanced, a 3-element meter should be used.

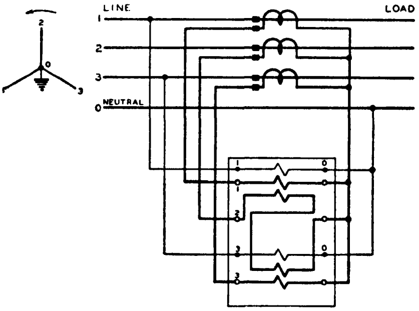


Fig. 7-22. (*right*) Measurement of Energy in a 3-Phase, 4-Wire, Wye Circuit by Means of a 2-Element, 4-Wire, Split Coil Meter with Current Transformers

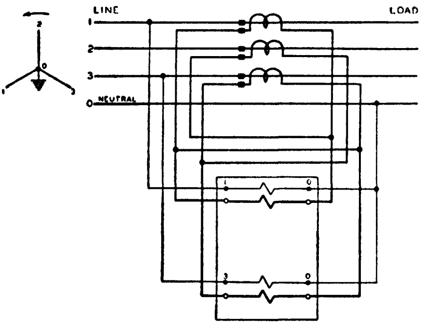


Fig. 7-23. (*left*) Measurement of Energy in a 3-Phase, 4-Wire, Wye Circuit by Means of a 2-Element Meter and Delta-connected Current Transformers

This method of metering a 3-phase, 4-wire, wye load has an application where a 3-element meter shown in Fig. 7-20, and the 2-element, split coil meter of Figs. 7-21 and 7-22 are not available. Care should be taken that the proper potentials are applied to the two potential coils.

The accuracy of this method, like that of the 2-element, 4-wire, wye meter, is based on the assumption that the negative vectorial sum of the two phase voltages equals the third phase voltage.

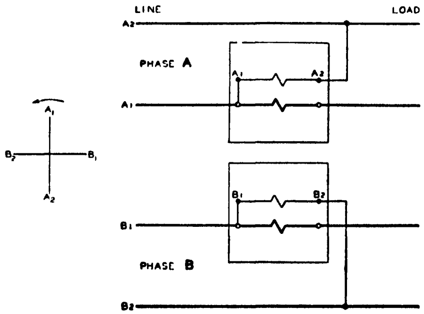


Fig. 7-24. (*right*) Measurement of Energy in a 4-Wire, 2-Phase Circuit Using Two Single-phase Meters

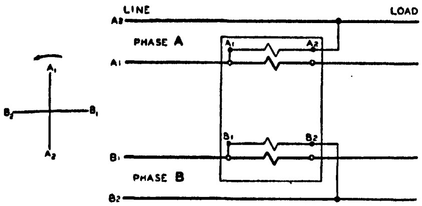


Fig. 7-25. (*left*) Measurement of Energy in a 4-Wire, 2-Phase Circuit Using a 2-Element Meter

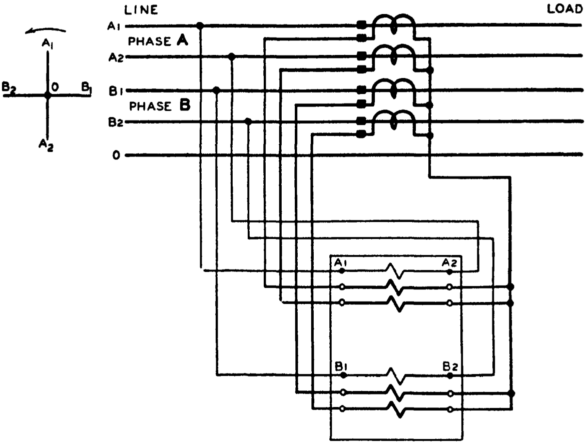


Fig. 7-26. Measurement of Energy in a 5-Wire, 2-Phase Circuit Using a 2-Element, 5-Wire Meter and Four Current Transformers

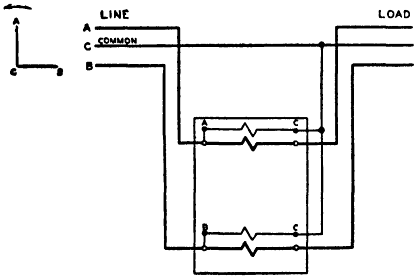


Fig. 7-27. (*left*) Measurement of Energy in a 3-Wire, 2-Phase Circuit with a 2-Element Meter

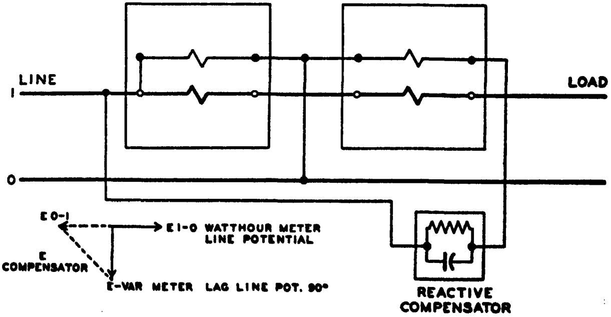

KWH
KVAR HR
LINE
1
LOAD
0
E O-I
E I-O WATTHOUR METER LINE POTENTIAL
E COMPENSATOR
E-VAR METER LAG LINE POT. 90°
REACTIVE COMPENSATOR

Fig. 7-28. (*right*) Measurement of Varhours in a Single-phase Circuit

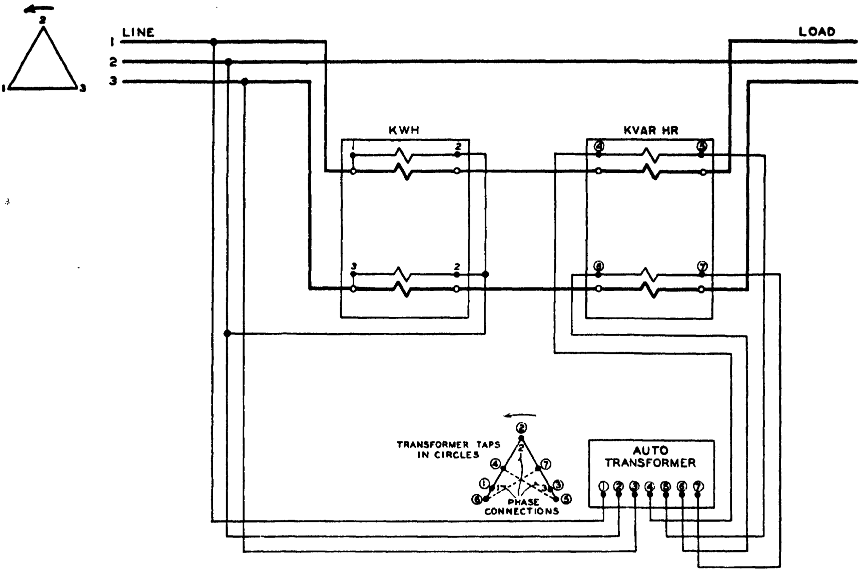


Fig. 7-29. Measurement of Varhours in a 3-Wire, 3-Phase Circuit Using a 2-Element Meter and Autotransformer. See Figs. 7-14, 7-15 and 7-16 for Measurement of Energy Only

The autotransformer used should be suitably rated for the maximum voltages applied, that is, a 240-volt autotransformer should be used on a 240-volt delta circuit. The tap markings on some autotransformers may differ from that shown.

Care should be taken that the voltages applied to a varhour meter are equal in magnitude and lag by 90° the voltages applied to the watthour meter.

The phase sequence of the voltages must be considered in connecting a varhour meter.

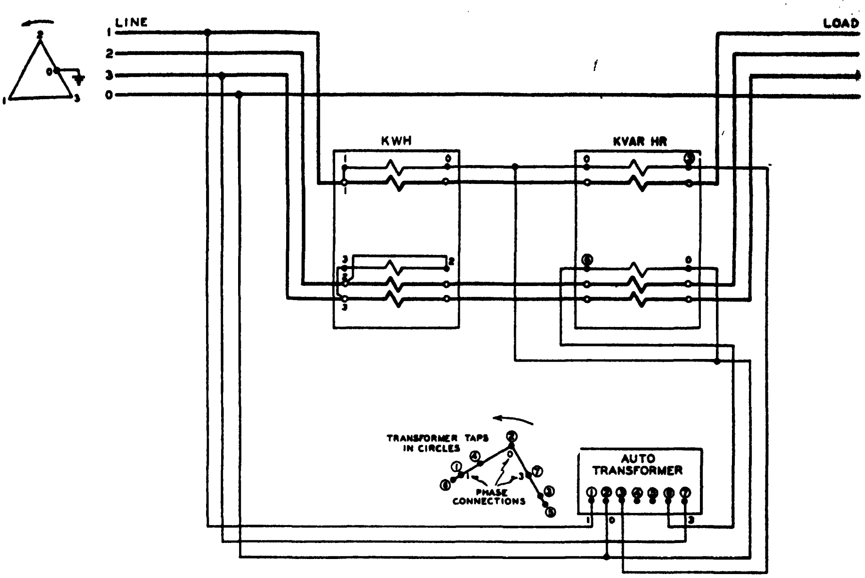


Fig. 7-30. Measurement of Varhours in a 3-Phase, 4-Wire Delta Circuit Using a 2-Element Meter and 3-Wire Autotransformer. See Figs. 7-17 and 7-18 for Measurement of Energy Only

The autotransformer used should be suitably rated for the maximum voltages applied, that is, a 240-volt autotransformer should be used on a 240-volt delta circuit. The tap markings on some autotransformers may differ from that shown.

Care should be taken that the voltages applied to each element of the varhour meter are equal in magnitude and lag by 90° the corresponding voltages applied to the watt-hour meter.

The phase sequence of the voltages must be considered in connecting a varhour meter.

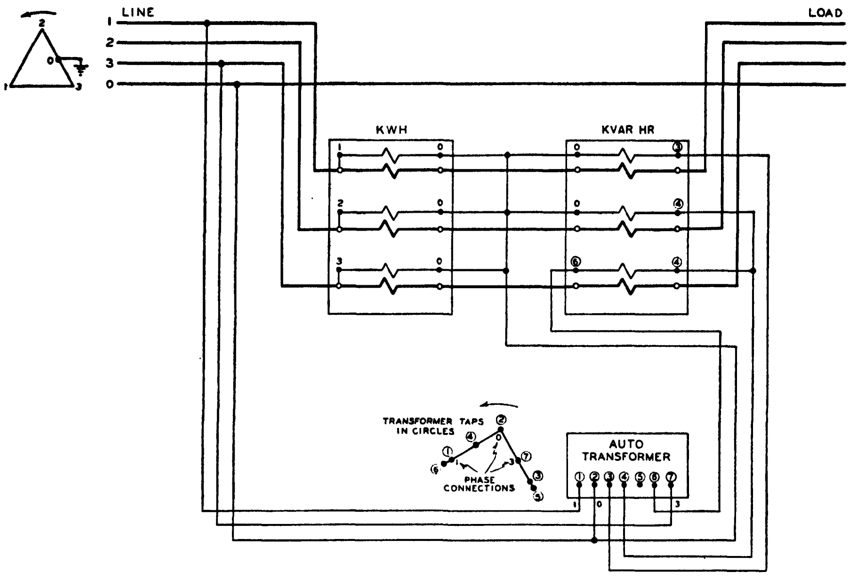


Fig. 7-31. Measurement of Varhours in a 3-Phase, 4-Wire, Delta Circuit Using a 3-Element Delta Meter and a 3-Wire Autotransformer. See Figs. 7-17 and 7-18 for Measurement of Energy Only

The autotransformer used should be suitably rated for the maximum voltages applied, that is, a 240-volt autotransformer should be used on a 240-volt delta circuit. The tap markings on some autotransformers may differ from that shown.

Care should be taken that the voltages applied to each element of the varhour meter are equal in magnitude and lag by 90° the corresponding voltages applied to the watthour meter.

The phase sequence of the voltages must be considered in connecting a varhour meter.

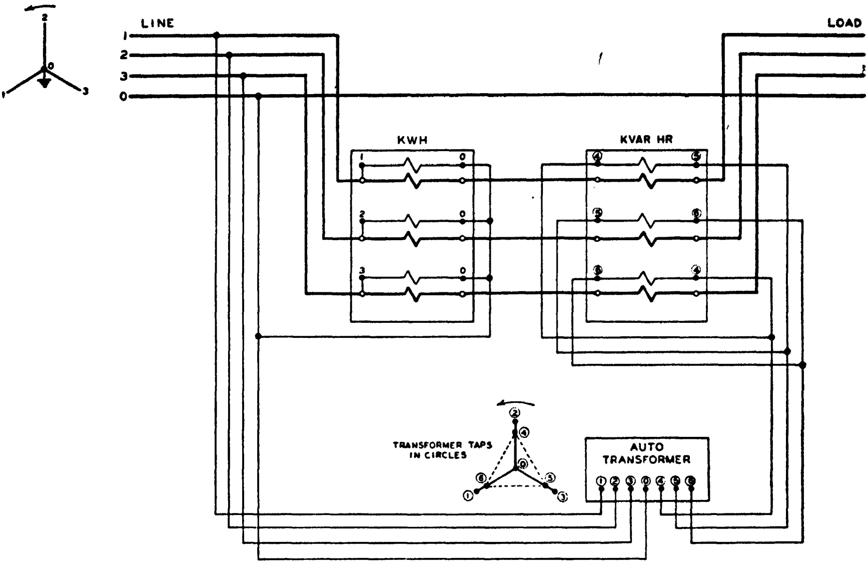


Fig. 7-32. Measurement of Varhours in a 3-Phase, 4-Wire, Wye Circuit Using a 3-Element Meter and a 4-Wire Autotransformer. See Figs. 7-20, 7-21 and 7-22 for Measurement of Energy Only

The tap markings on some autotransformers may differ from that shown. Care should be taken that the voltages applied to a varhour meter are equal in magnitude and lag by 90° the voltages applied to the watthour meter.

The phase sequence of the voltages must be considered in connecting a varhour meter.

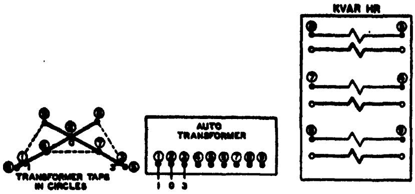


Fig. 7-33. (*left*) Another Type of Autotransformer That May Be Used with the Varhour Meter Shown in Fig. 7-32

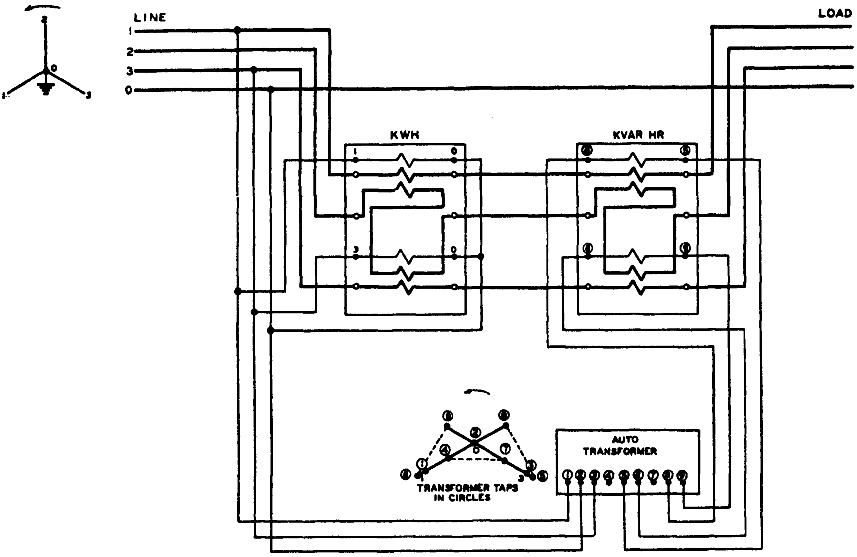


Fig. 7-34. Measurement of Varhours in a 3-Phase, 4-Wire, Wye Circuit Using a 2-Element, 4-Wire, Split Coil Meter and a 4-Wire Autotransformer. See Figs. 7-20, 7-21 and 7-22 for Measurement of Energy Only

The tap markings on some autotransformers may differ from that shown. Care should be taken that the voltages applied to a varhour meter are equal in magnitude and lag by 90° the voltages applied to the watthour meter.

The phase sequence of the voltages must be considered in connecting a varhour meter.

(Note: The autotransformer shown above has taps simillar to the 2-coil, 3-phase, 3-wire autotransformer illustrated in Fig. 7-29 and may be used interchangeably with it.)

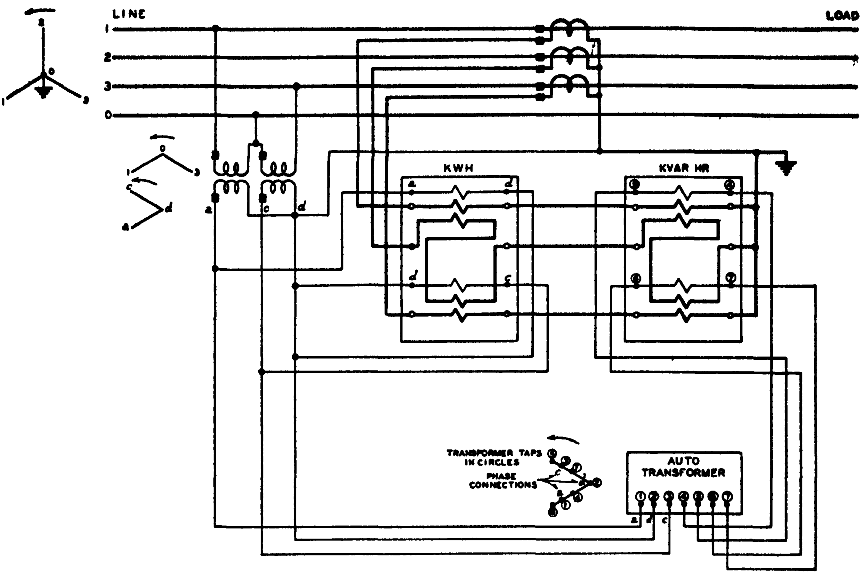


Fig. 7-35. Measurement of Varhours in a 3-Phase, 4-Wire, Wye Circuit Using Instrument Transformers, a 3-Wire Autotransformer and a 2-Element, 4-Wire, Split Coil Meter

The use of a 3-wire autotransformer on a 4-wire circuit is made possible by reversing one of the phase voltages; this can be accomplished where potential transformers are used for metering. The alternative method of using a 4-wire autotransformer is shown in Fig. 7-34.

The tap markings on some autotransformers may differ from that shown. Care should be taken that the voltages applied to a varhour meter are equal in magnitude and lag by 90° the voltages applied to the watthour meter.

The phase sequence of the voltages must be considered in connecting a varhour meter.

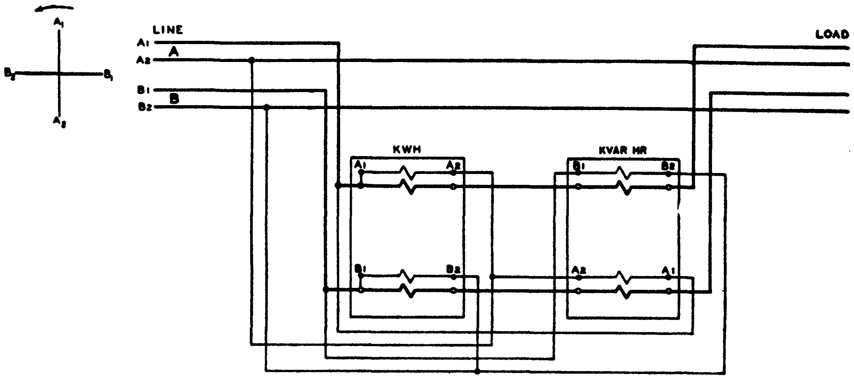


Fig. 7-36. Measurement of Varhours in a 2-Phase, 4-Wire Circuit with a 2-Element Meter. See Fig. 7-25 for Measurement of Energy Only

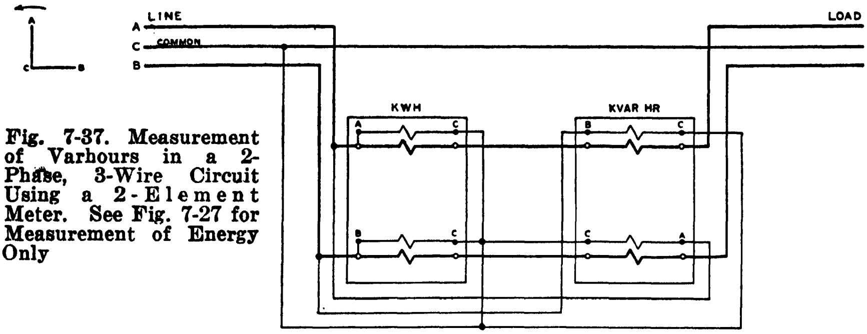


Fig. 7-37. Measurement of Varhours in a 2-Phase, 3-Wire Circuit Using a 2-Element Meter. See Fig. 7-27 for Measurement of Energy Only

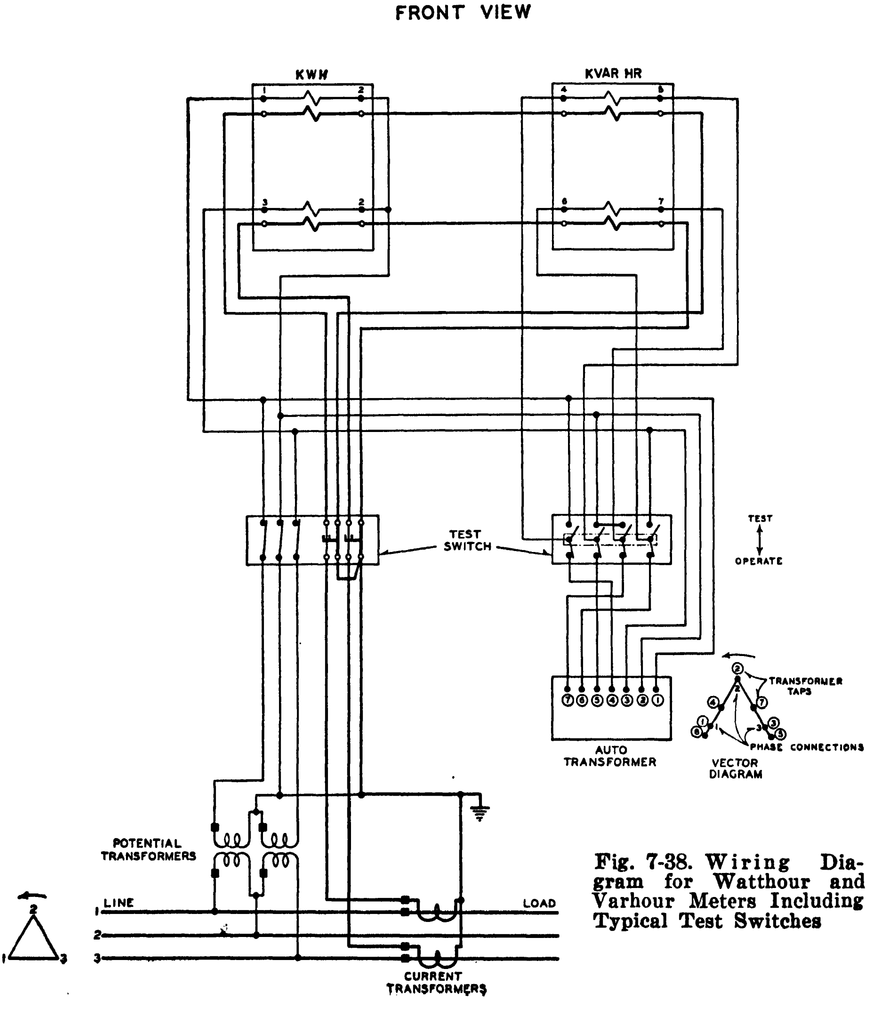
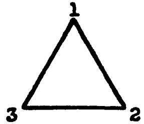
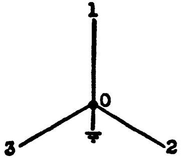
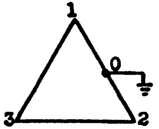


Fig. 7-38. Wiring Diagram for Watthour and Varhour Meters Including Typical Test Switches

STANDARDIZED TERMINAL MARKINGS FOR PHASE-SHIFTING DEVICES DESIGNED FOR APPLICATION ON SPECIFIC TYPES OF SERVICES

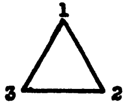
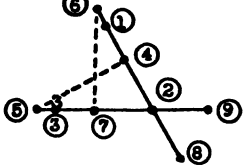
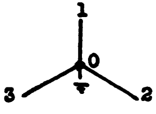
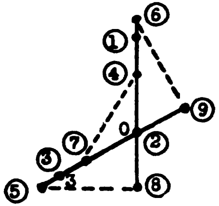
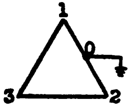
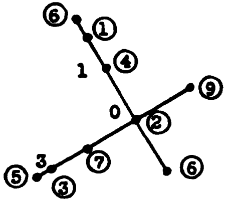
Type of Service	Line Connections Phase to Terminal	Potential Connections	
		Kwhr Meter	Kvarhr or Kvahr Meter
3-Phase 3-Wire △ 	1 — ① 2 — ② 3 — ③	1 → 2 3 → 2	④ → ⑤ ⑥ → ⑦
3-Phase 4-Wire Y 	1 — ① 2 — ② 3 — ③ 0 — ⓪	3-Element 1 → 0 2 → 0 3 → 0	④ → ⑤ ⑥ → ⑦ ⑧ → ⑨
	1 — ① 3 — ③ 0 — ⓪	2-Element 1 → 0 3 → 0	④ → ⑤ ⑧ → ⑨
3-Phase 4-Wire △ 	1 — ① 2 — ② 3 — ③ 0 — ⓪	3-Element 1 → 0 2 → 0 3 → 0	④ → ⑤ ⑥ → ⑦ ⑧ → ⑨
		2-Element 1 → 2 3 → 0	④ ⑤ ⑧ ⑨

NOTE: Potential Connections Shown Are For Forward Rotation Of Meter Disc On 1 - 2 - 3 Phase Sequence And Lagging Current.

Numerals In Circles Represent Terminal Markings On The Phase-Shifting Devices.

Fig. 7-39. Standardized Terminal Markings for Phase-Shifting Devices Used in Metering

APPLICATION OF A UNIVERSAL PHASE-SHIFTING DEVICE ON COMMON TYPES OF SERVICES

Type of Service	Phase-Shifting Device Connections And Vector Diagram	Line Connections Phase to Terminal	Potential Connections	
			Kwhr Meter	Kvarhr or Kvahr Meter
3-Phase 3-Wire Δ 		1 – ① 2 – ② 3 – ③	1 → 2 3 → 2	④ → ⑤ ⑥ → ⑦
3-Phase 4-Wire Y 		1 – ① 0 – ② 3 – ③	3-Element 1 → 0 2 → 0 3 → 0 2-Element 1 → 0 3 → 0	3-Element ⑧ → ⑤ ⑦ → ④ ⑥ → ⑨ 2-Element ⑧ → ⑤ ⑥ → ⑨
3-Phase 4-Wire Δ 		1 – ④ 0 – ② 3 – ③	3-Element 1 → 0 2 → 0 3 → 0 2-Element 1 → 2 3 → 0	3-Element ② → ⑦ ⑤ → ⑦ ① → ② 2-Element ② → ⑤ ① → ②

NOTE: Potential Connections Shown Are For Forward Rotation Of Meter Disc On 1 - 2 - 3 Phase Sequence And Lagging Current.

Numerals In Circles Represent Terminal Markings On The Phase-Shifting Devices.

Fig. 7-40. Application of a Universal Phase-Shifting Device on Common Types of Services

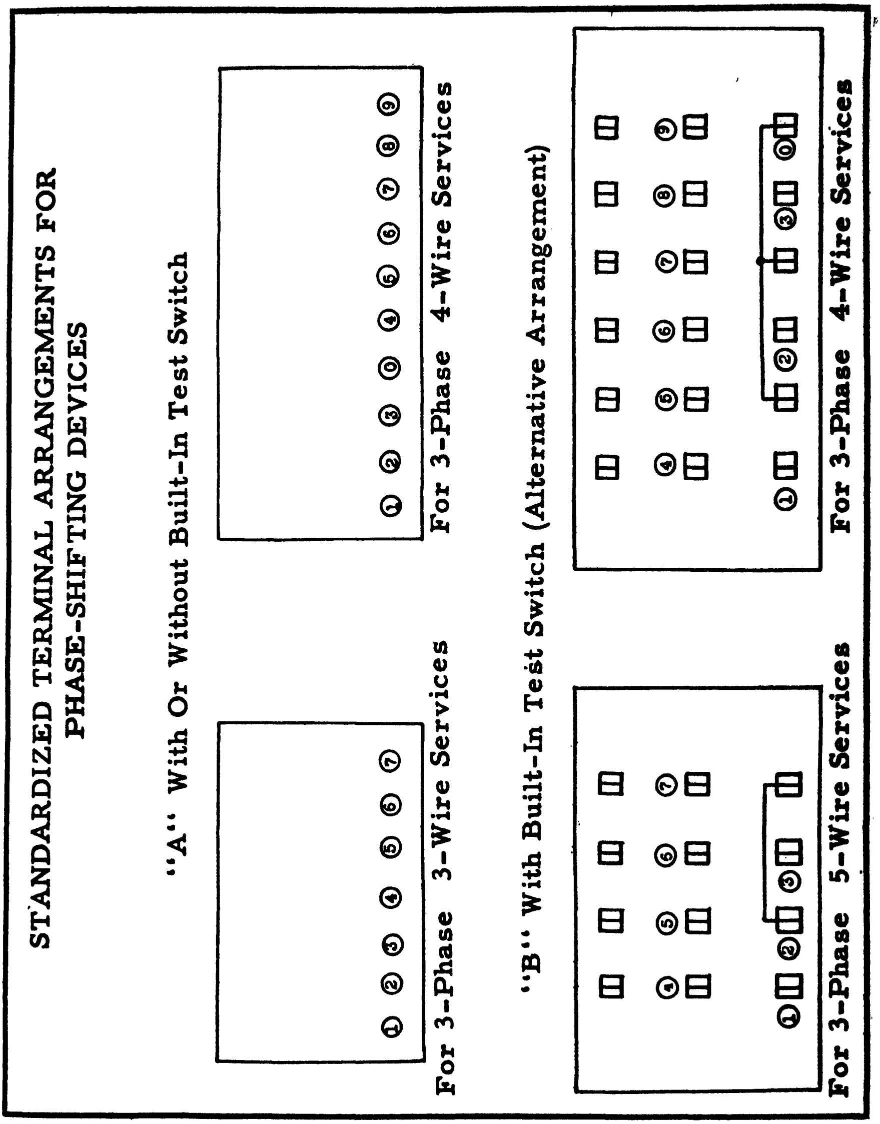

STANDARDIZED TERMINAL ARRANGEMENTS FOR PHASE-SHIFTING DEVICES
''A'' With Or Without Built-In Test Switch
① ② ③ ④ ⑤ ⑥ ⑦
For 3-Phase 3-Wire Services
① ② ③ ⓪ ④ ⑤ ⑥ ⑦ ⑧ ⑨
For 3-Phase 4-Wire Services
''B'' With Built-In Test Switch
④ ⑤ ⑥ ⑦
① ② ③
For 3-Phase 5-Wire Services
(Alternative Arrangement)
④ ⑤ ⑥ ⑦ ⑧ ⑨
① ② ③ ⓪
For 3-Phase 4-Wire Services

Fig. 7-41. Standardized Terminal Arrangements for Phase-Shifting Devices

SECTION 8

METER INSTALLATIONS

The selection of suitable metering equipment, the location of such equipment, and the use of economical installation methods are important considerations both from a company and a customer viewpoint.

SELECTION OF METERING EQUIPMENT

The watthour meter and its associated equipment selected for each installation should be chosen with a view to obtaining the best adaptation to local conditions and load. It should also be suited to the voltage, frequency and character of the service, these usually being fixed depending on the service to be supplied for a given installation.

The ampere capacity, however, is determined from the connected load and the demand factor for the particular installation. For small installations, it is practicable to establish arbitrary demand factors for various classes of customers. For larger installations, it is generally necessary to determine the specific load conditions in order to arrive at the demand factor.

In determining the size of watthour meters to be used, consideration should be given to the maximum demand and overload capacity of alternating-current meters. A modern 15-ampere meter is usually adequate for all residential installations, including range and water heater loads.

POWER INSTALLATONS

For individual motors, the meter capacity selected depends upon the starting current and the load characteristics of the motor. It should generally be equal to the current rating of the motor. Where several motors are connected to the same watthour meter, the starting current of the largest motor should be considered as well as the diversity factor of the load, which generally will be such that a meter of smaller capacity than the combined ampere rating of the motors may be used. For detailed information on the determination of motor current ratings, see the data and formulas in Tables 18-I and 18-J.

INSTALLATION PRACTICE

Good installation practice requires the consideration of the following:

1. Protection of service conductors and metering equipment.
2. Proper location.
3. Space requirements.
4. Adaptability of various types of meters.
5. Ease of installation, replacement, and test.
6. Provision for future requirements.

All American meters are now manufactured in one of two types of standard bases. The type A is the bottom terminal meter, and the type S is the rear terminal detachable meter. All type A meters in a specific class are interchangeable, and all type S meters in a specific class are interchangeable.

The type A meter is generally installed in conjunction with an enclosure. There are several forms of enclosures available, varying from enclosure of the meter terminal chamber only to total meter enclosure. Types suitable for outdoor installation are designed to protect the meter from the weather.

The type S meter is installed in conjunction with a socket. There are two types of sockets: a single unit containing the necessary terminals and wiring enclosure and suitable for connection directly to the service conduit or cable; and a multiple unit type for installation in trough or wiring channel designed primarily for group installation. The socket or trough unit forms the enclosure for the wiring as well as the mounting for the meter. Single sockets may be used either indoors or outdoors and the trough type is available for both indoor and outdoor service.

Service and Meter Location

The location of the service and the metering equipment is an important consideration to both the customer and the company. The location of the service on a customer's premises is a determining factor in the meter location. Both should be located so that the installation will be economical and convenient for the customer and the company.

Meter locations should be readily accessible, with a minimum of annoyance to the customer, for reading and testing. The mounting locations should be free of excessive vibration. Thought should be given to the possibility of excessive vibration caused by the operation of heavy switchgear.

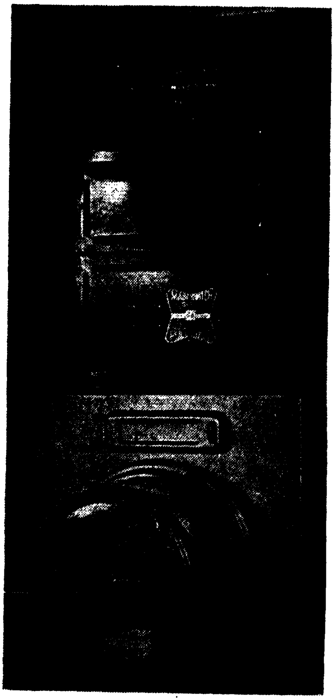


Fig. 8-1. Meter and Service Installation. Socket Meter and Service Switch and Fuses

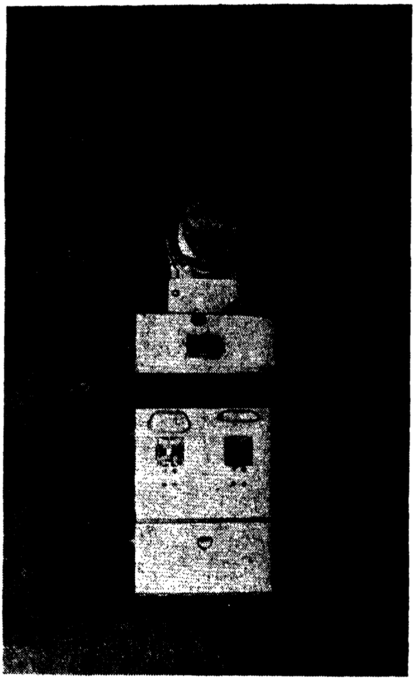


Fig. 8-2. Single Meter with Connection Box and Combination Service Switch

Indoor Installations—Meters should, in general, be mounted with the bottom not less than four feet and the top not more than seven feet from the floor in a secure manner in a clean, dry, safe place, relatively free from extremes in temperature.

It is preferable on residential installations that meters be installed on the ground floor or in the basement. They should not be installed in closets, coal bins, over doors or on insecure partitions, nor in close proximity to machinery, stoves, radiators, wash trays, or steam or gas piping. Figs. 8-1, 8-2 and 8-3.

In large office and apartment buildings, meter space of ample size should be provided. The company should keep the architects and contractors informed as to its practice for meter and service installations.

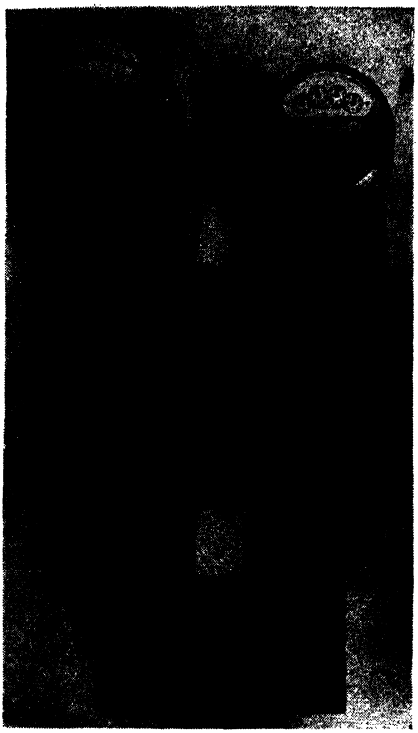


Fig. 8-3. Service and Meter Installation. Watthour and Demand Meters and Service Switch

Where meters are grouped, the circuit to which each one is connected should be plainly indicated, and all circuits should be carefully traced to insure that no error exists in the wiring whereby one customer obtains service through another customer's meter. Figs. 8-4, 8-5, 8-6, 8-7 and 8-8.

When polyphase watthour meters are installed, especially when used with instrument transformers, care should be taken to insure proper connections in accordance with the manufacturer's diagram, attention being given to the polarity markings of the instrument transformers. In addition a check should be made to insure that the meter will operate correctly. Fig. 8-9.

Outdoor Installations — Meters located outdoors should, in general, be mounted at least three feet from the ground or standing level and in a location which does not detract appreciably from the appearance of the building. The outdoor meter installation is adaptable to either overhead or underground services. See Figs. 8-10 to 8-16 for typical installations.

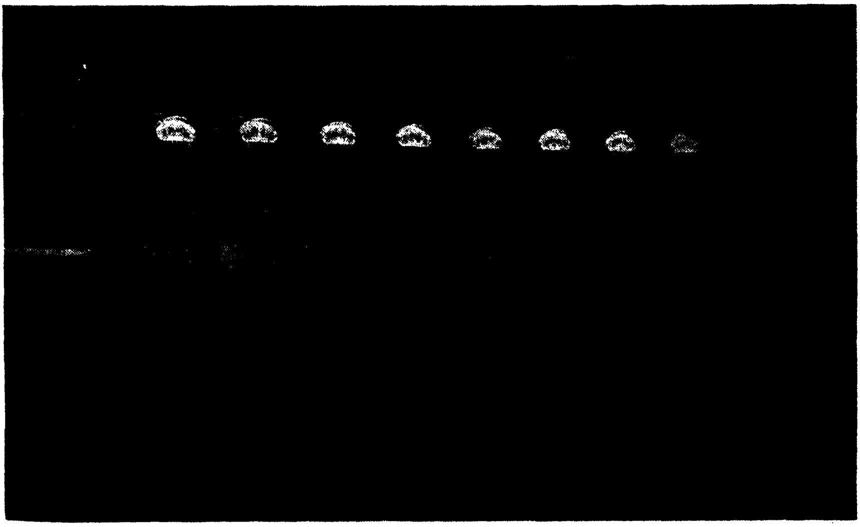


Fig. 8-4. Group Installation of Type "A" Meters with Terminal Chamber Enclosures

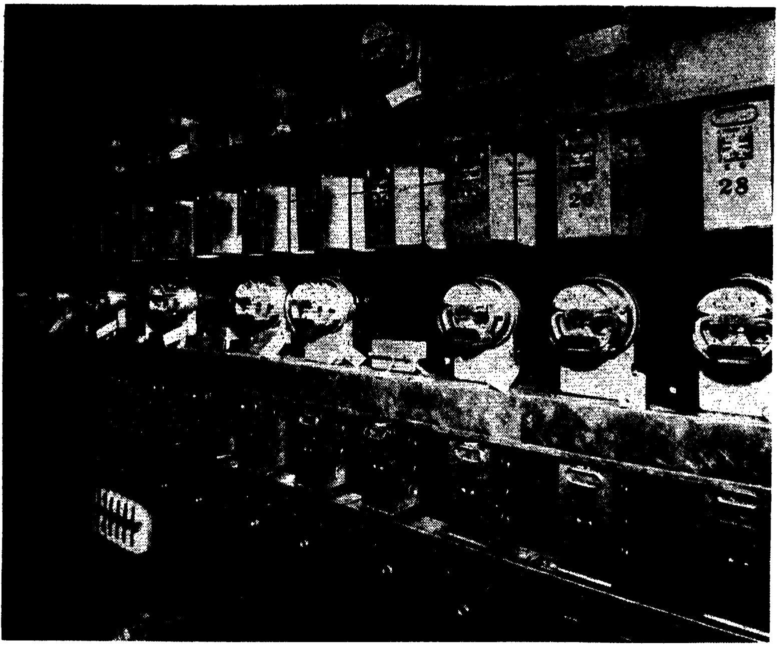


Fig. 8-5. Group Installation, Bottom-connected Meters

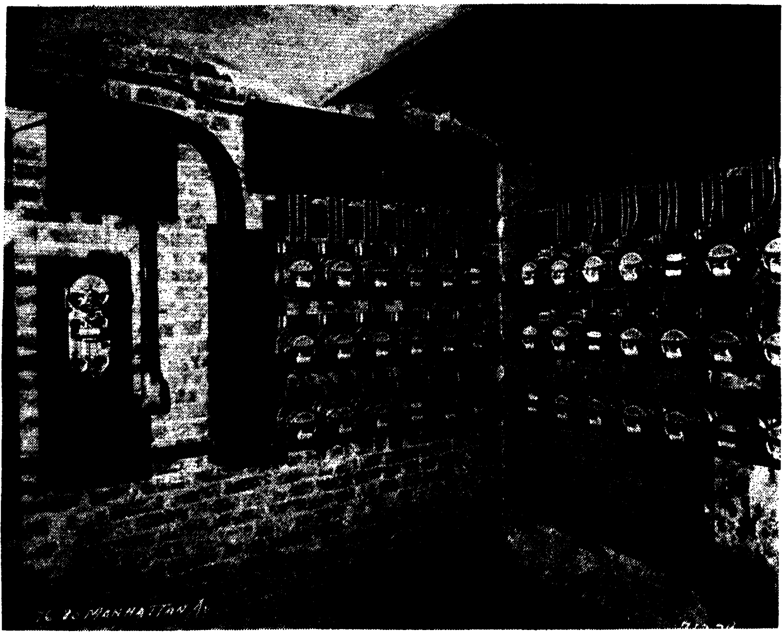


Fig. 8-6. Socket Meter Installation Using Troughs Having Test Facilities

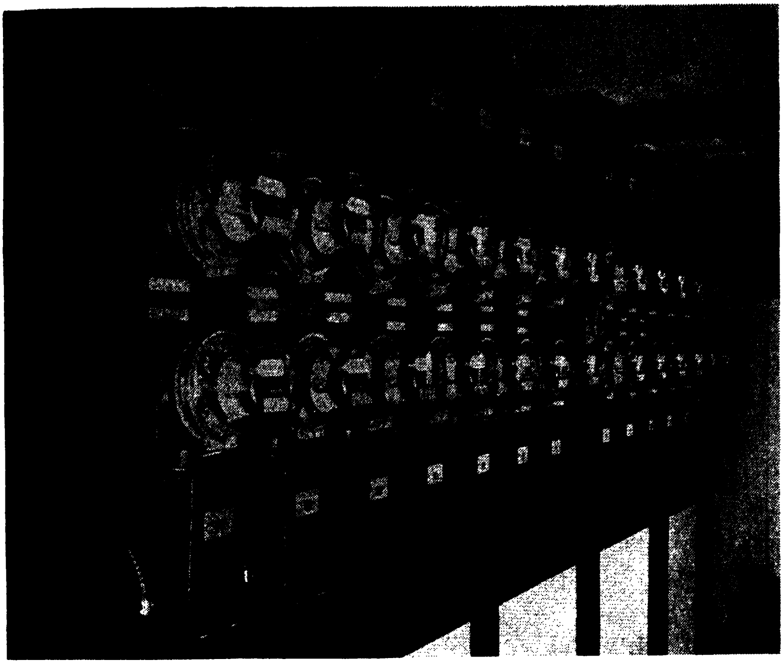


Fig. 8-7. Group Installation of Socket Meters with Troughs

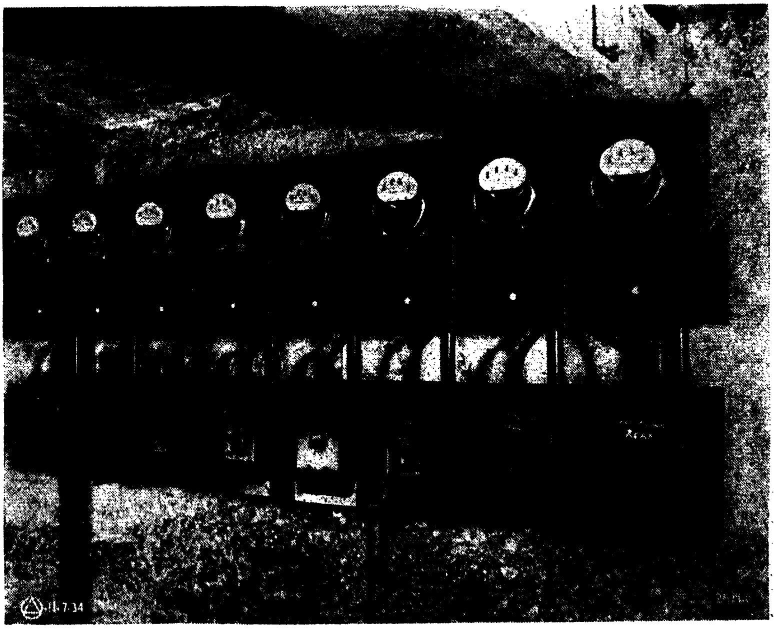


Fig. 8-8. Group Installation of Type "A" Meters in Enclosures

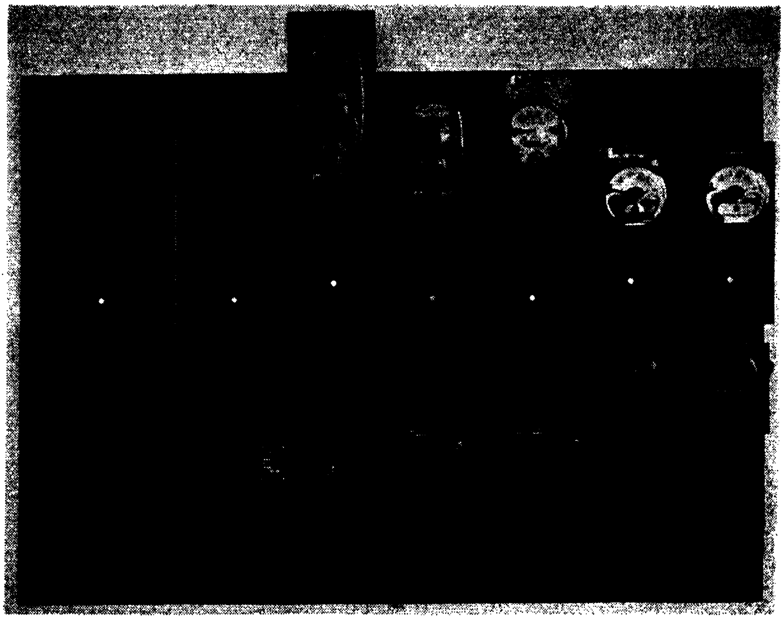


Fig. 8-9. Type "A" Meters Mounted in Meter Enclosures on Wiring Channel Together with Polyphase Meters

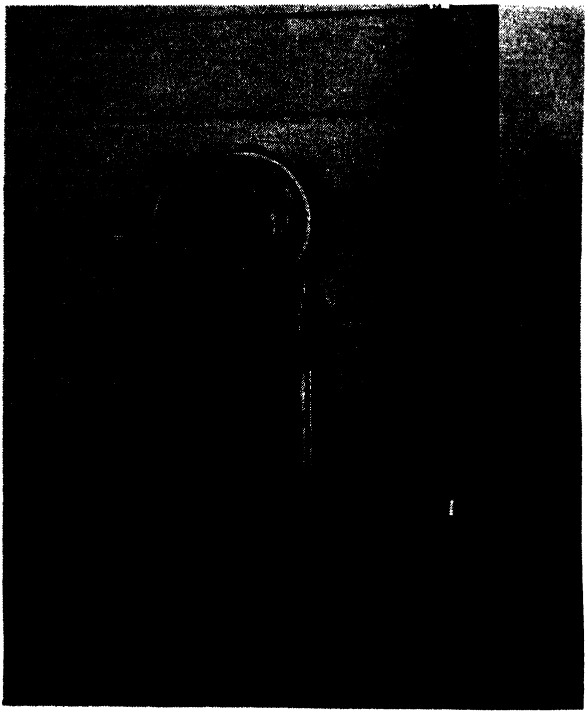


Fig. 8-10. Outdoor Installation of Type "A" Meter with Terminal Chamber Enclosure

Fig. 8-11. Type "A" Meter Installed Outside in Steel Enclosure. Service Cable from Pole to Meter

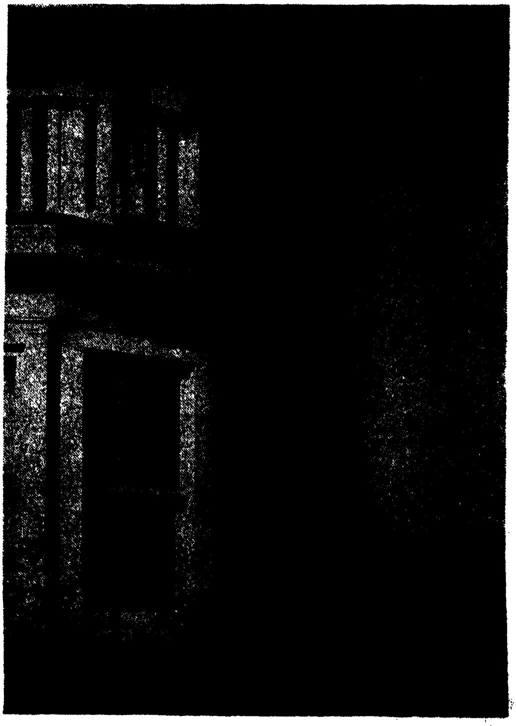


Fig. 8-12. Outdoor Socket Meter (on rear of building). Overhead Service Cable from Pole to Meter. Example of Good Selection of Location to Avoid Detracting from Appearance

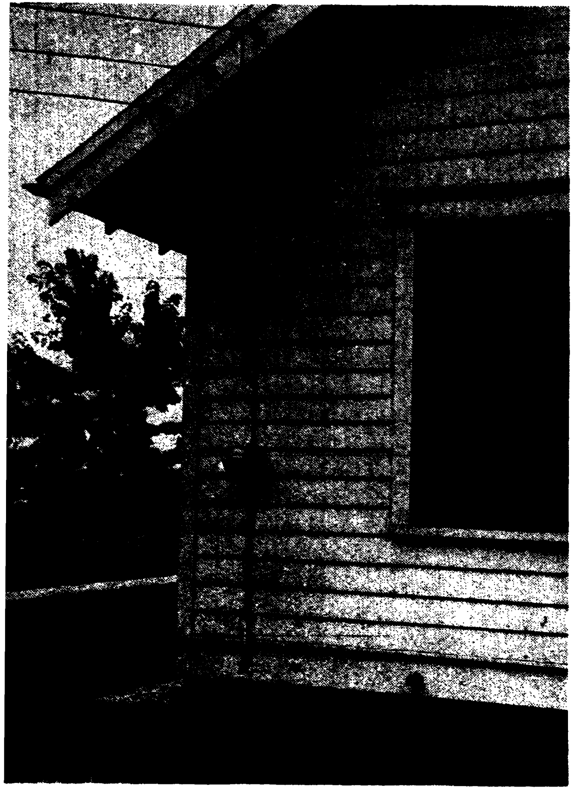
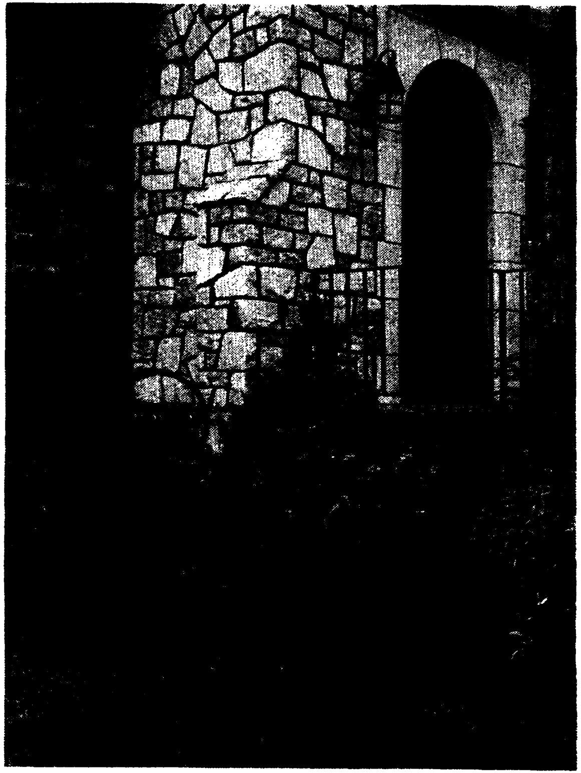


Fig. 8-13. (*left*) Residential Outdoor Socket Meter Installation. Three-conductor Service Cable Installed Down Side of Building

Fig. 8-14. (*right*) Outdoor Meter Installation, 2 Watthour Meters and Time Switch, Underground Service. Example of Good Selection of Location to Avoid Detracting from Appearance of Building



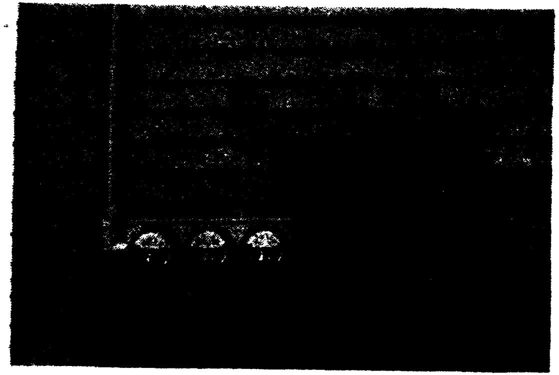


Fig. 8-15. Multiple Outdoor Meter Installation Using Socket Meter Trough

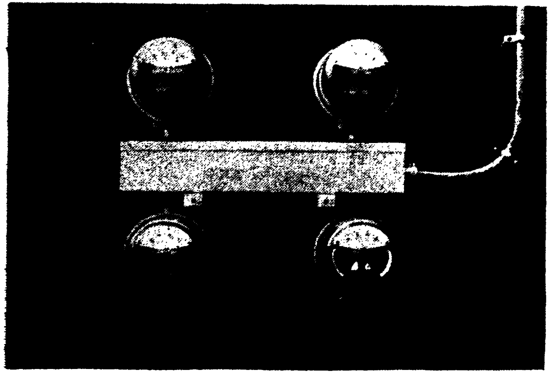


Fig. 8-16. Individual Socket Meters Installed Outdoors with Wiring Trough

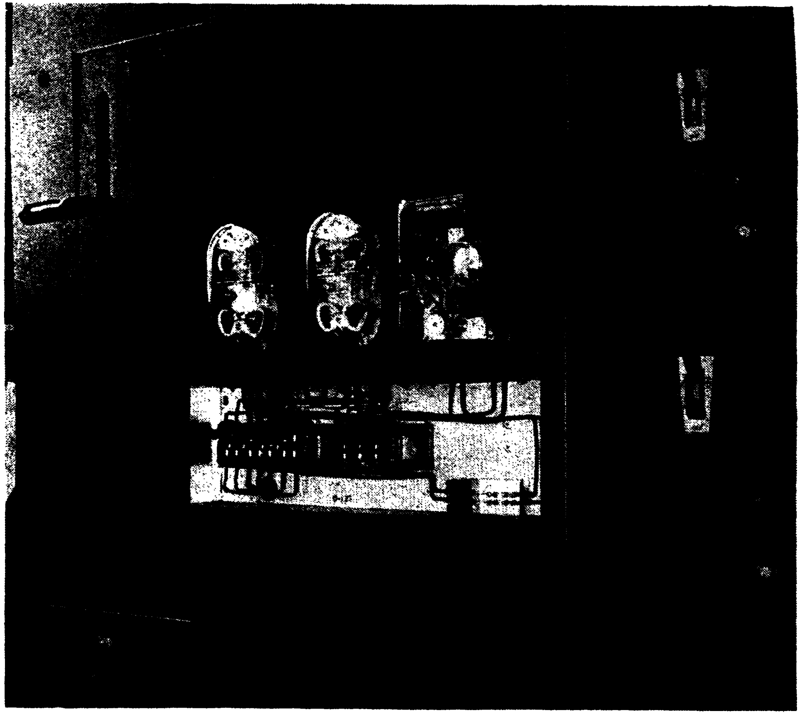


Fig. 8-17. Watthour Meter, Varhour Meter, Relay Demand Meter, and Test Switch Assembly with Cover Removed

Primary Metering

Secondary meters, in conjunction with instrument transformers, are utilized in metering high voltage circuits. Figs. 8-17 and 8-18.

Outdoor type current and potential transformers, indoor type transformers in a suitable enclosure, or metering outfits in weatherproof enclosures are installed on poles, structures or in substations. Figs. 8-19, 8-20, 8-21, 8-22, 8-23, 8-24, and 8-25. Primary metering is usually associated with measurements of large blocks of power; therefore, careful consideration should be given to the location of meters and metering equipment. Indoor locations for meters are preferable, particularly when demand devices are associated with the metering equipment. An outdoor meter house of sufficient dimensions to permit a meter tester full protection from the weather is acceptable where the indoor location is not available. The use of an outdoor meter box for this purpose does not permit efficient maintenance of metering devices under varying weather conditions. Fig. 8-26.

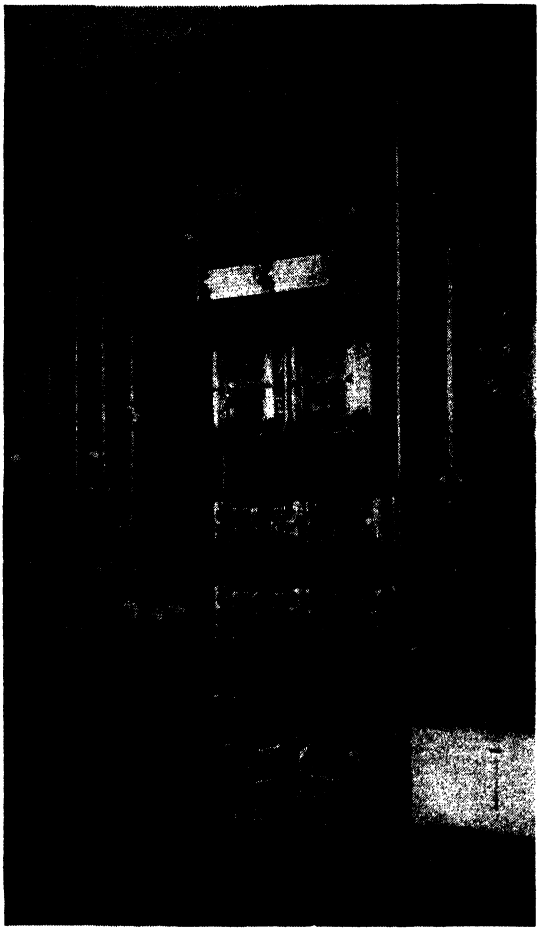


Fig. 8-18. Meter Panel for 132-kv Interconnection Showing Graphic Demand Meters for Energy Measurement and Varhour Meters for Power Factor Determination

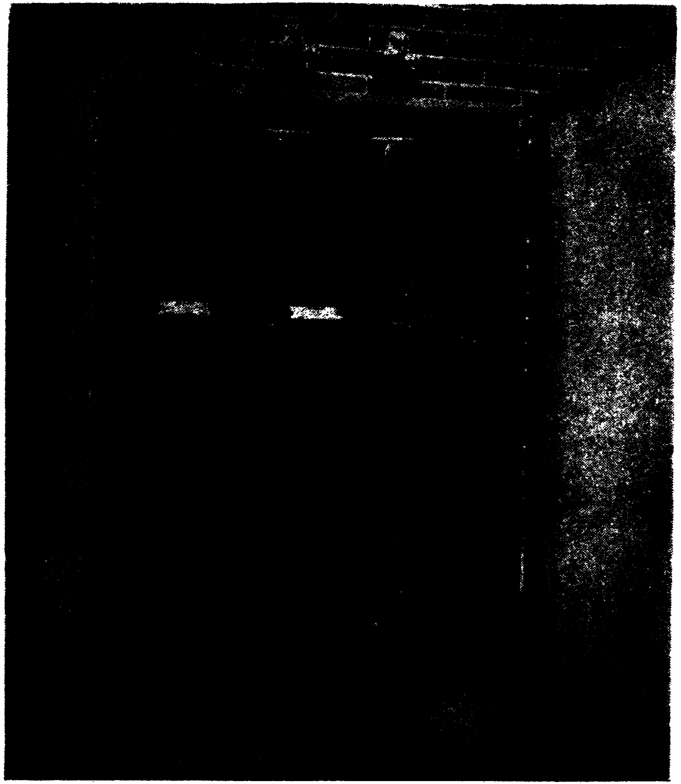


Fig. 8-19. Indoor Type Instrument Transformers Mounted In Enclosure for Outdoor Installation

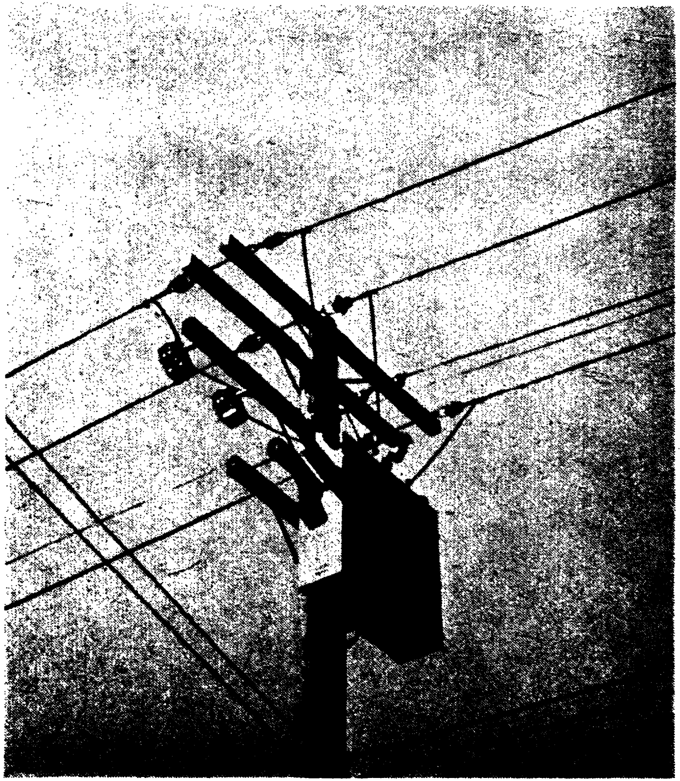


Fig. 8-20. Instrument Transformer Enclosure Mounted on Distribution Pole

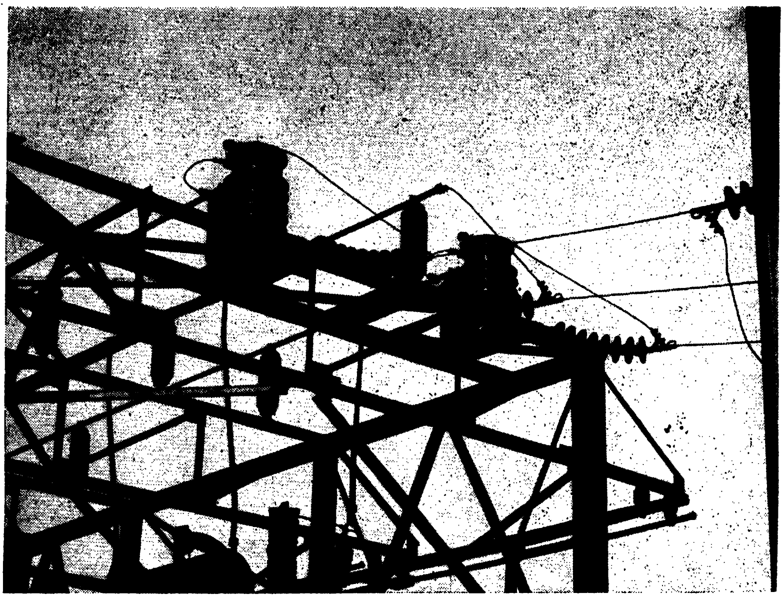


Fig. 8-21. 66-kv Installation Showing Compactness and Mounting Adaptability of Modern Porcelain-clad Outdoor Current Transformers

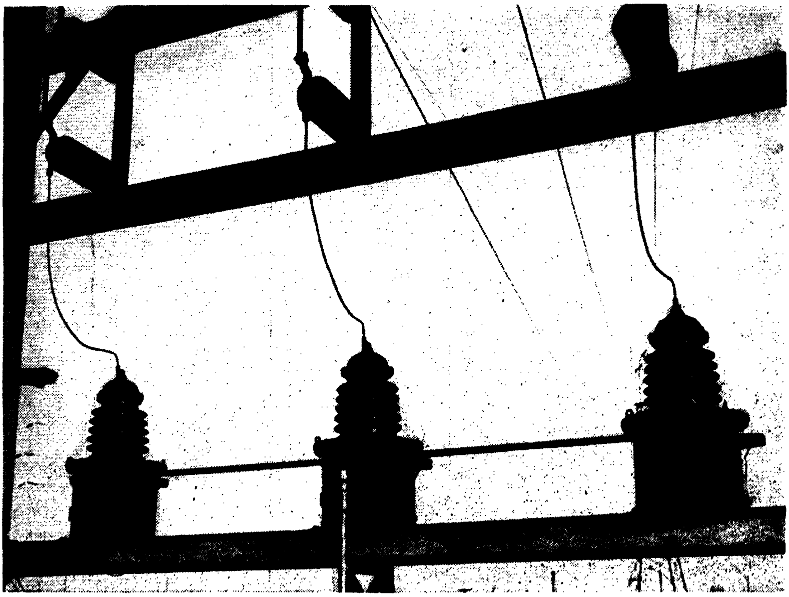


Fig. 8-22. 66-kv Installation Showing Compactness and Mounting Adaptability of Modern Single-bushing Outdoor Potential Transformers

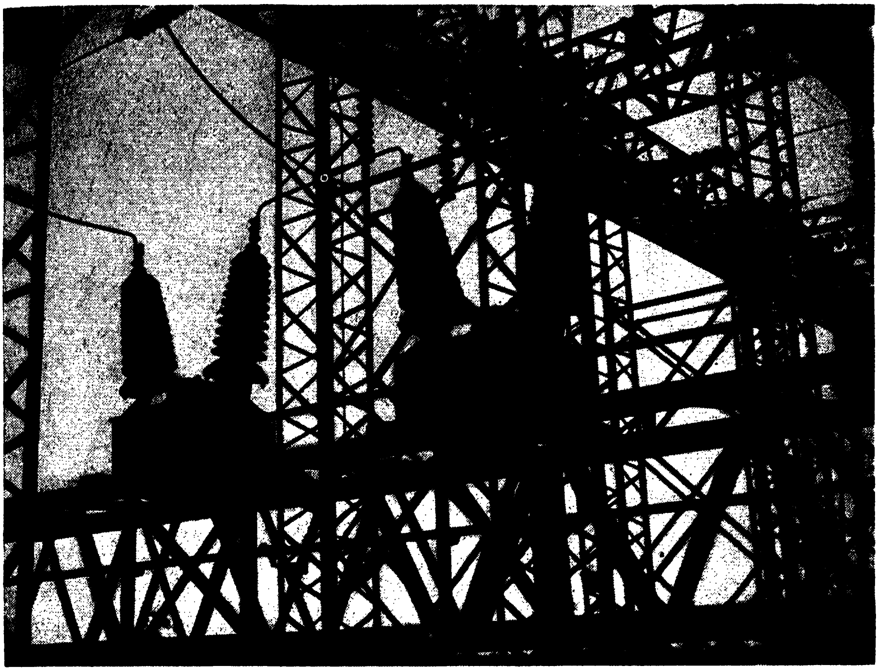


Fig. 8-23. 66-kv Installation Showing Compactness and Mounting Adaptability of Modern Double-bushing Outdoor Potential Transformers

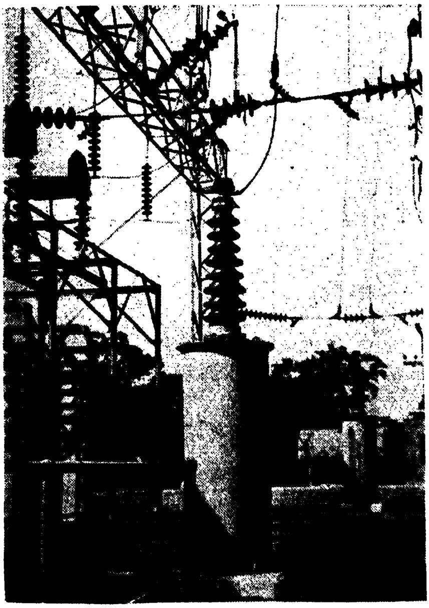


Fig. 8-24. Current Transformers for 132-kv Metering

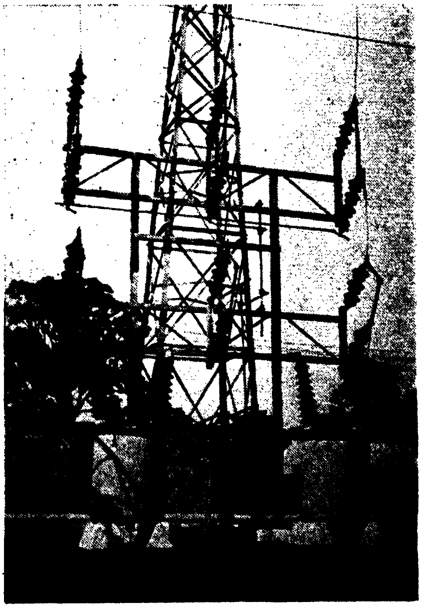


Fig. 8-25. Potential Transformers for 132-kv Metering

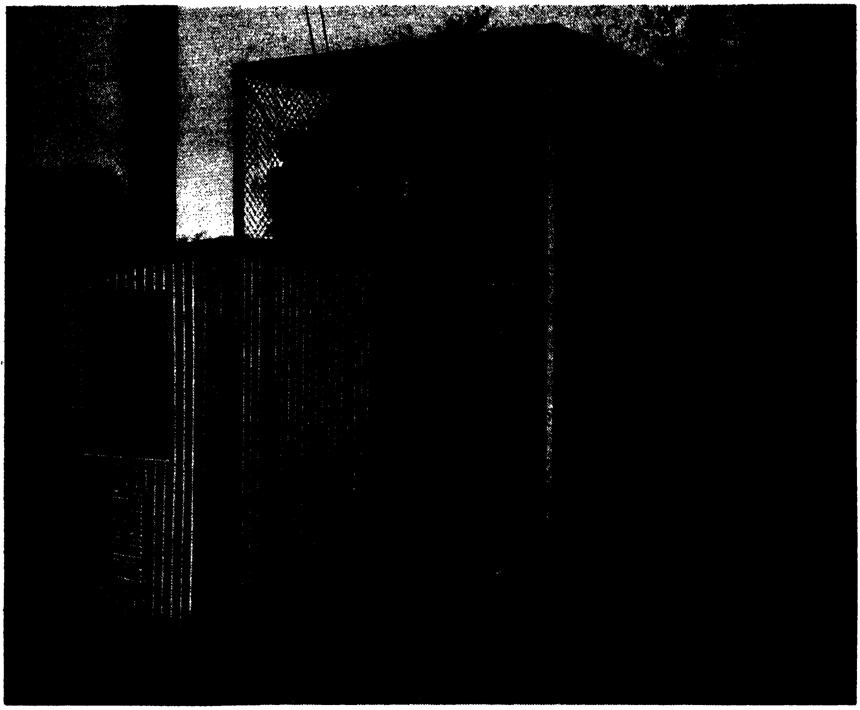


Fig. 8-26. A Type of Meter House Which Provides Adequate Protection and Space for Maintenance Work on Meters

The choice of potential transformers for a primary installation is guided, within well-defined limits, by the circuit arrangement and voltage. However, for highest overall accuracy, efficiency and economy, the selection of current transformer ratings must be based on a proper evaluation of several important factors. These include not only the connected load, the expected maximum demand and the load power factor, but also future load expectations, the range of demand readings, and the light-load registration provided by the metering combination.

Installation of Demand Meters

A wide choice of demand devices is available to suit the various metering practices and rate structures now applied as well as the load conditions of the services to be metered. These may be in the form of indicating or graphic meters, directly geared or contact-operated, mechanical or thermal, and combination watthour-demand or separate demand meters.

While, in general, the location of demand meters may be the same as that of the corresponding watthour meters, it should be noted that demand meters operated by spring-driven clocks are affected to a greater degree by large temperature changes than are watthour meters. Most modern demand meters are operated with synchronous motors and are not so seriously affected by temperature changes. Certain types of recording devices may also be affected by low temperatures or excessive moisture. In dusty locations such as cement and flour mills, dust-tight auxiliary covers may be necessary.

Demand meters operating with wax charts give the best record when working in temperatures of about 60 to 80 degrees Fahrenheit. At 100 to 125 degrees Fahrenheit the wax will usually melt and the record will be lost. If instruments of this type are to be operated at low ambient temperature, auxiliary heating should be applied to maintain the temperature between 60 and 80 degrees Fahrenheit.

Provision for Future Metering Requirements on Customers' Installations

In cases where the load to be metered is only a fraction of the installed service capacity it is wise to make adequate provision for the future metering of possible load increases toward full installed service capacity. This is particularly important where increases in load may necessitate a change from self-contained to transformer type metering, or where the increase involves a change in tariff requiring a different metering method. Obviously, the surest way to avoid difficulties, delays and further expense for the customers or the operating company when such installations must be changed, is to key all requirements for metering space and for equipment to be installed by customers to the service capacity rather than the load to be metered immediately. Although this system may at times seem to require an initially excessive outlay of equipment and space, it will prove itself advantageous in the greater flexibility, efficiency and economy with which later changes in metering may be made.

Inactive Service Practice

It is usual practice to leave meters in place for a reasonable period, at least in certain classes of buildings, such as residences, apartments and offices where occupants are changing so frequently that the prospects of a new tenant at an early date are reasonably sure.

In such buildings, leaving the meters in place is undoubtedly an economical practice and reduces the time required in providing service for a new occupant.

In commercial and industrial classes of business, the practice of leaving meters on vacant premises is not generally followed. The reason is that the new load is usually of a different character and alterations are probable, requiring a relocation or change in the metering equipment. Furthermore, the possibilities of damage to, or loss of the meter during such alterations are much greater. The usual practice is to remove the meters at the time the service is discontinued, unless definite information is available as to the succeeding tenant and his plans.

It is essential that all meters left on inactive service be visited periodically to guard against damage and unauthorized use. Some companies adopt the practice of continuing the reading sheets in the meter route books, so that a monthly report is received on the conditions, while other companies obtain readings less frequently but sufficient to insure the safety of service and to prevent its unauthorized use.

SECTION 9

ROUTINE METER TESTING

A watthour meter consists essentially of a driving element which establishes a torque on a disk proportional to the power to be measured, a permanent magnet which opposes the driving torque in proportion to the speed, and a registering mechanism connected by suitable gearing to register the number of revolutions of the rotating element.

Testing a watthour meter consists of determining whether the number of revolutions of the rotating element of the meter is correct for a given amount of energy and whether the intermediate and register gearing of the meter is correct to translate properly the revolutions into appropriate units. The test of a watthour meter is accomplished by comparing its registration with that of standard instruments. For watthour meters the measured unit is the kilowatthour.

See the 1923 edition of the *Handbook for Electrical Metermen*, Chapters VI and VII, for information on direct-current meter testing.

TEST METHODS

The principal requirements of an acceptable test method are accuracy and economy. Minor variations from, or amplifications of, the methods outlined may be used. Such deviations will depend upon local conditions affecting the work; such as number and ratings of the meters, character and extent of the territory served, and the requirements of regulatory bodies. Tests are made both in the meter shop and in service on the customers' premises.

The acceptable methods in use for meter testing are:

1. Portable standard watthour meter method
2. Indicating instrument method
3. Stroboscopic method.

Portable Standard Watthour Meter Method

In this method of test a portable standard watthour meter, sometimes referred to as the standard, is used. It usually has multiple current and potential windings. It is connected in series with the meter under test, and the revolutions of the standard are compared with the revolutions of the meter under test for the same interval of time, allowance being made in the calculations for the disk constants of the two meters. In all cases the range of the standard best suited to indicate accurately the quantity being measured should be used. Standards should be handled with care, both in transportation and use, to avoid mechanical or electrical injury.

Although stray fields have little effect on induction-type standards, care should be taken to keep them away from heavy current carrying conductors, motors, transformers and other apparatus. A strong field, either alternating or non-pulsating in close proximity to a standard may cause errors in registration.

This method is less susceptible to errors due to variations in test load than other methods, since both the meter and the standard integrate the same values. In service testing the value of the load is best determined from the known approximate ratings of the various steps in the loading device.

Where the value of the load is unknown, it may be determined by timing the standard with a stop watch and computing the value of the watts from the equation:

$$\text{true watts} = \frac{\text{rev} \times \text{watthour constant} \times 3600}{\text{seconds}}$$

With this method of testing two types of loading devices are in general use, the *resistance load* and the loading transformer or *phantom load*. Figs. 9-14 and 9-15.

The connections for testing are as follows: The current coil of the standard is connected in series with the loading device and meter under test, and the potential coil of the standard is connected in parallel with the potential coil of the meter under test. See Figs. 9-14 to 9-26, inclusive. When setting up a standard for making a test, a place should be selected reasonably free from vibration and magnetic influence.

The load should be entirely disconnected at the meter or test block to preclude the possibility of an error in the results due to a load or leakage in the customer's circuit.

A portable standard watthour meter is usually operated by a switch in the potential circuit, which starts or stops the standard. A reading of the standard is taken at the beginning and end of the test and the difference between these two readings gives the number of revolutions of the standard. If no correction is to be applied to the standard readings, the percentage registration of the watthour meter under test is obtained as follows:

let r = revolutions of meter under test
R = revolutions of standard
k_h = watthour constant of meter under test
K_h = watthour constant of standard

then

percentage registration =

$$\frac{k_h \times r}{K_h \times R} \times 100.$$

The method may be facilitated by introducing an additional symbol, values for which may be given to the tester in tabular form.

Let R_o = the number of revolutions the standard should make when the meter under test is correct.

The number of revolutions of two watthour meters on a given load vary inversely as their disk constants.

$$\frac{R_o}{r} = \frac{k_h}{K_h}$$

$$R_o = \frac{k_h \times r}{K_h}$$

Substituting R_o in the equation for percentage registration:

$$\text{percentage registration} = \frac{R_o}{R} \times 100$$

Example:—

The watthour meter under test and the standard have the following constants:

meter $k_h = 0.6$
standard $K_h = 0.12$

The number of revolutions of the meter under test, $r = 2$

$$\text{then } R_o = \frac{0.6 \times 2}{0.12} = 10$$

that is, for 2 revolutions of the meter under test, the standard should make 10 revolutions. Assume the standard actually made 10.16 revolutions, then:

percentage registration =

$$\frac{10}{10.16} \times 100 = 98.4$$

When a correction is to be applied to the readings of the standard, the percentage registration is determined as follows:

let A = percentage registration of standard

then percentage registration =

$$\frac{k_h \times r \times A}{K_h \times R}$$

Another type of control is to start and stop the meter under test. This

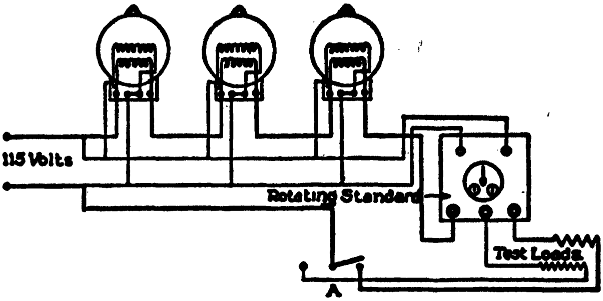


Fig. 9-1. Diagrammatic Arrangement of Simplified Form of Start and Stop Method

is primarily a shop method. The meter is started, run on a specific load and stopped at the end of a predetermined number of revolutions of a standard watthour meter. For example, if a load of 500 watts is applied for 21.6 seconds (0.006 hour) to a meter having a disk constant of 0.3 watthour, at 100% registration the disk of the meter should make 10 revolutions from start to stop.

$$\frac{500 \times 0.006}{0.3} = 10 \text{ revolutions}$$

If the disk under the above conditions made 9.99 instead of 10 revolutions, the registration of the meter would be 99.9%; but if it made 10.15 revolutions, the registration would be 101.5%.

This type of control may be applied to testing of individual meters or to several meters of the same size and test constant in series. Fig. 9-1.

For group testing, the potential circuits of each meter and the standard must be connected to the source at the same points in order that all of the meters and the standard may have the same potential; the potential current of one meter must not pass through the current coils of any of the other meters. With the marks on the disks of the meters under test opposite some reference point such as the opening between the magnets, load is applied by means of the switch A, for an interval sufficient to cause the standard to make the number of revolutions equivalent to ten revolutions of the meters under test, which will be

$$\text{revolutions of standard} = \frac{10 \times k_h}{K_h}$$

The percentage registration of a meter is determined directly at the end of a test by the displacement of the mark on the disk from the reference point as shown on a scale similar to that illustrated in Fig. 9-2.

Recent developments in shop testing equipment make use of the photo-

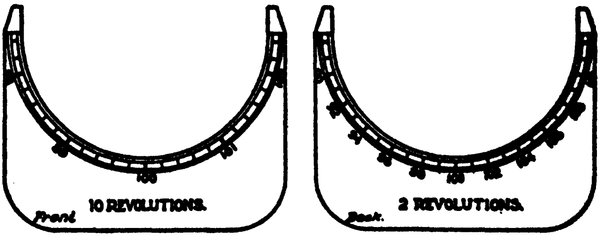


Fig. 9-2. Typical Scale Used For Determining the Accuracy of Meters Under Test by Start and Stop Method

electric tube for automatically starting and stopping the standard watthour meter. For this method of test a light beam is focused on the disk of the watthour meter under test and in the line of travel of the anticreep holes by lenses in the light source. Thus the light beam passes through the anticreep holes in the disk onto a phototube beneath, which causes impulses to be transmitted to the control equipment. These impulses are then amplified and used to operate automatic switches and relays controlling the potential circuit of the standard. This is done in accordance with a predetermined number of revolutions of the watthour meter disk.

As an alternate to the use of anticreep holes, a switch is provided in the control equipment so that reflections from the surface of the disk can be used. The black mark on the disk then becomes the reference point. Fig. 9-3 is a schematic diagram of the equipment.

This method of shop testing eliminates the necessity of counting the revolutions of the meter disk and since the starting and stopping of the standard is automatic, personal errors are eliminated.

Indicating Instrument Method

Load is applied to the meter and watthours are measured by means of indicating instruments and timing devices such as stop watches or chronographs. The time is usually that required for some convenient and predetermined number of revolutions of the meter under test. The procedure is as follows: the time required for an integral number of revolutions of the meter is measured by a stop watch, and the power, in true watts, during the same period is measured by means of indicating instruments. The ratio between the

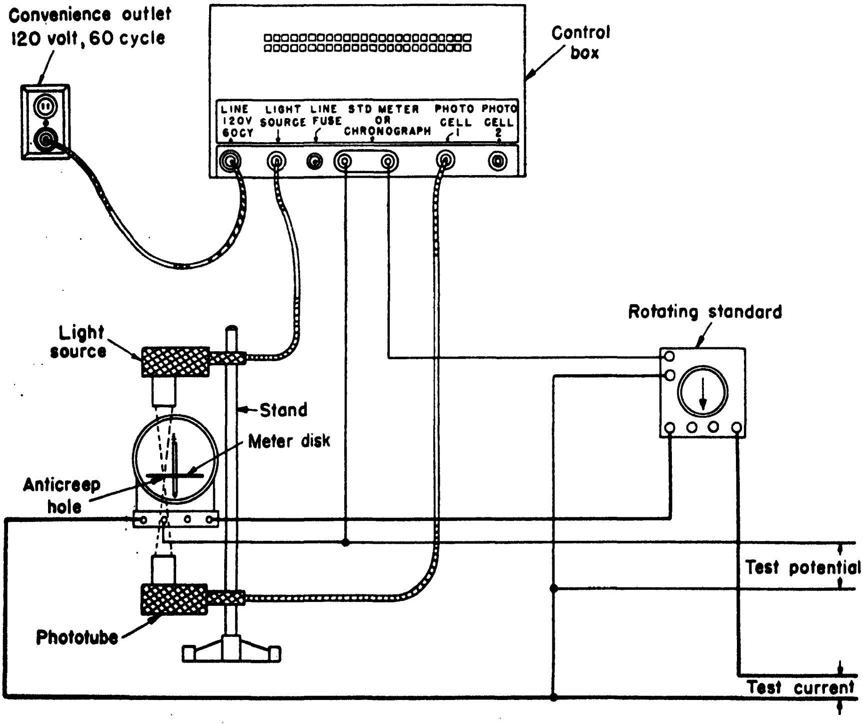


Fig. 9-3. Schematic Diagram of Photo-electric Testing Equipment

indicated or meter watthours and the true watthours multiplied by 100 is the percentage registration of the meter under test.

Example:—

let

P = true watts (average watts by indicating instruments)
k_h = watthour constant
r = number of revolutions of disk
s = time in seconds for r revolutions

then,

$$\text{meter watthours} = k_h \times r$$
$$\text{meter wattseconds} = k_h \times r \times 3600$$
$$\text{meter watts} = \frac{k_h \times r \times 3600}{s}$$

Percentage registration of the meter may then be determined from the following equation:

$$\text{percentage registration} = \frac{k_h \times r \times 3600 \times 100}{P \times s}$$

Indicating instruments to measure direct-current power may be a voltmeter and ammeter, or a wattmeter. A wattmeter is required to measure alternating-current power. This method is generally limited to special meter tests.

Stroboscopic Method

Stroboscopic methods have been universally used for accurate measurement of speed. They depend upon the principle that if a uniformly rotating device is illuminated by a flash of light once per revolution, it will appear to be stationary. If the speed of the device is slightly faster than that of the light flashes, it will appear to revolve slowly in its actual direction of rotation; if the speed of the device is slightly slower than that of the light flashes, it will appear to revolve slowly in the opposite direction.

If the revolving device consists of n number of identical sections, it will appear to be stationary if illuminated by n number of flashes per revolution.

Fig. 9-5 shows a stroboscopic testing unit for testing watthour meters. In this device the light coming from the light source is interrupted by the standard so as to produce pulsating light depending upon the speed of the

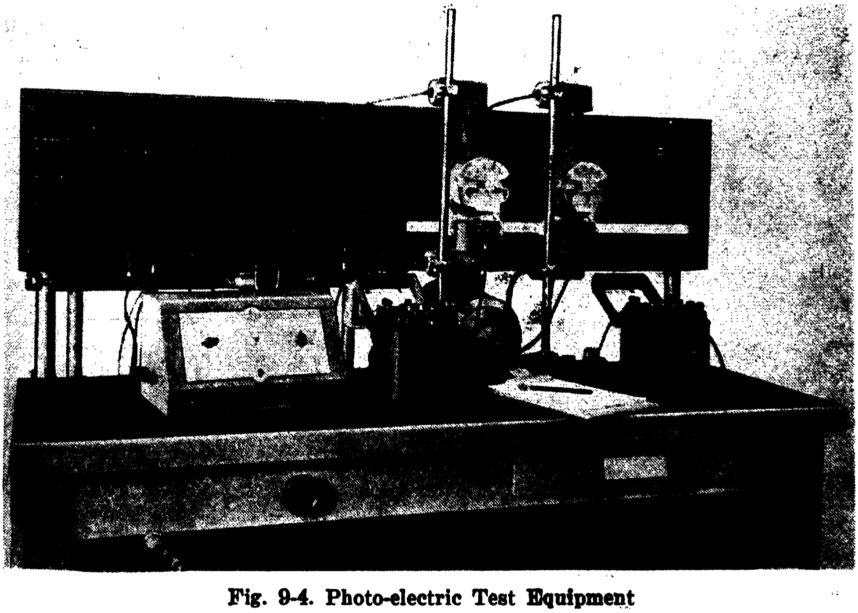


Fig. 9-4. Photo-electric Test Equipment

standard. The pulsating light coming from the standard is intercepted by the disk of the meter under test and may be viewed directly or amplified through a viewing attachment on a ground glass screen.

Since both meters are connected in series, any change in load will affect both meters simultaneously so that resultant stroboscopic action is not affected. When using this equipment, the operator selects the switches for either a full-load, light-load, or lag test. If the stroboscopic marks under any one of the foregoing tests are not stationary, the required adjustment is made so that the marks will appear stationary.

In order that *as found* tests can be made on meters, a percentage registration indicator may be added to this testing unit. It consists of an autotransformer and potentiometer arrangement whereby the voltage on the standard is either raised or lowered. The movement of the potentiometer is calibrated directly in percentage registration. This method can be applied where the standard used has a straight-line voltage curve. To eliminate the necessity of changing the standard for the various ratings of meters tested, a high accuracy current transformer is provided.

The stroboscopic method of meter testing finds application in meter shops having a large number of meters to test. It is not limited as to the type of meter to be tested except that marking or slotting of the disk is necessary. Newer type disks are marked for this purpose, Fig. 9-6.

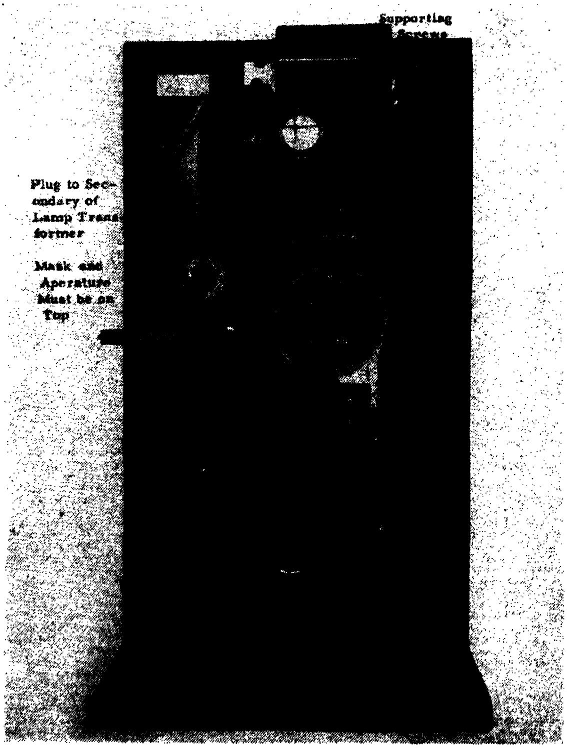

Supporting Screws
Plug to Secondary of Lamp Transformer
Mask and Aperature Must be on Top

Fig. 9-5. Stroboscopic Meter Testing Outfit

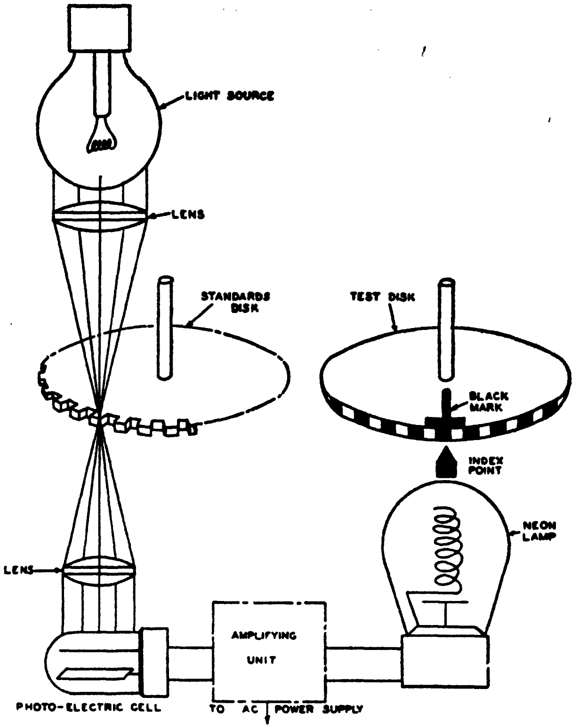


Fig. 9-6. Schematic Arrangement of Stroboscopic Meter Testing Apparatus

SERVICE TESTS

The practice of installing meters for residential service outdoors emphasized the problem of testing meters in service during parts of the year when weather conditions make it impossible or very inconvenient. As a consequence, two methods of periodic testing are in general use. They are as follows:

1. Field tests in place of service.
2. Replacing meters for shop test in a central location.

Depending on local conditions, each method is worthy of careful consideration and each has definite advantages and disadvantages which are summarized briefly.

Field tests in place of service

Advantages

Handling and transportation of meters eliminated.

No record changes necessary.

Does not interrupt normal billing procedure.

Disadvantages

Inconvenient during inclement weather when outdoors.

Working conditions not always satisfactory.

Only minor maintenance work can be done conveniently.

Replacing meters for shop test

Advantages

Ideal testing conditions.

Best facilities for maintenance work.

Improved supervisory control.

Disadvantages

Requires record change.

Interrupts normal billing procedure.

Requires handling and transportation of meters.

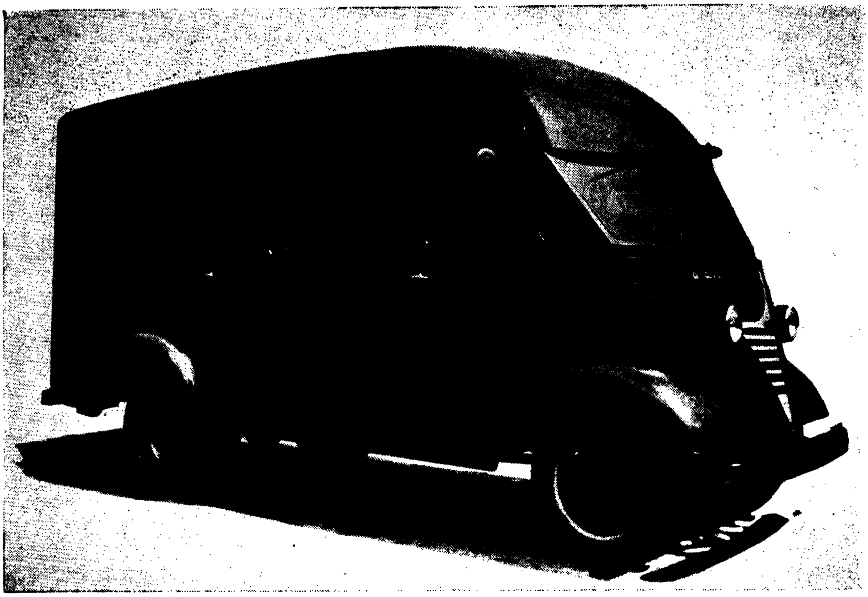


Fig. 9-7. Outside View of Mobile Testing Unit

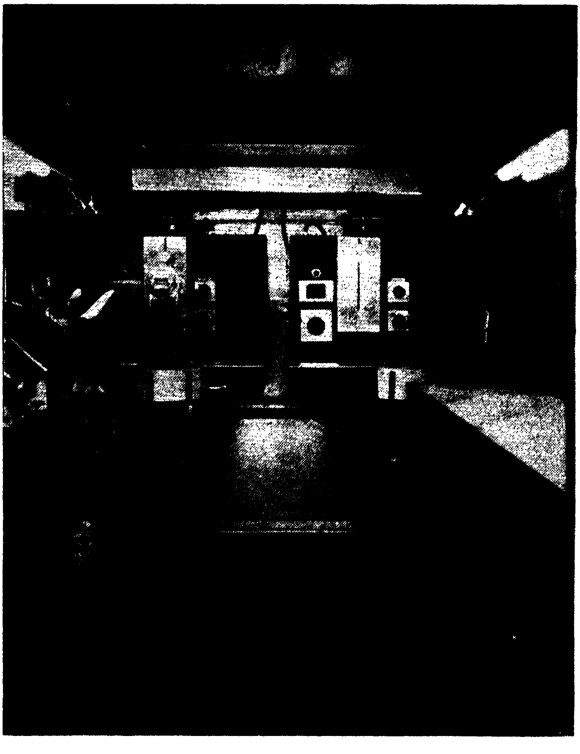


Fig. 9-8. Inside View of Mobile Testing Unit

A third method, using a mobile testing unit or portable meter shop, is a newer development and has had only limited use. The unit makes use of a standard truck chassis on which is mounted a body especially designed for the purpose. Fig. 9-7 is an outside view of the unit and Fig. 9-8 is an inside view.

Service to the mobile testing unit is obtained by clamping a cable to the distribution secondaries.

Its economic use is confined to cities and towns having an appreciable number of single-phase meters remote from the meter shop. Since the efficiency of the plan depends on area testing as distinguished from due date testing, all meters in the area are removed for test. After test, they are re-installed on the same locations from which they were removed.

Periodic Test Routine

Periodic tests of meters are made:

1. To obtain the percentage registration of the meter "as found" and to check the register and other meter constants.
2. To clean, readjust and recalibrate the meter.
3. To verify the "as left" percentage registration.

Rules of Procedure—General

Before attempting to enter the premises or to work on the meter, the tester should in general make known his presence to the customer or his representative, identify himself as a representative of the company, and show evidence of authority to test the meter by exhibiting his badge or identification card.

All records should be neat and legible and all test entries and computations should be made at the time the work is done. The record of any test should include the serial numbers or some definite identification of all instruments used.

Testing Routine

The work should be done in a definite order. This applies to tests made either in the shop or in service. For a complete test and adjustment, the procedure is as follows:

1. Make the *as found* test and record data.
2. Clean the meter thoroughly, removing any dust or dirt with special attention to the magnet poles.
3. Remove and examine the register, first having recorded the reading.
4. If the light-load test indicates friction, clean all bearings, and replace if necessary.
5. Check the position of the disk in relation to the magnet poles; center if necessary.
6. Calibrate the meter, making all necessary adjustments described heretofore.
7. Clean the cover and examine for defects.
8. Make *as left* test and record data.

Under certain conditions in the field, it may be deemed advisable to take no further steps if the "as found" tests show that the meter is operating satisfactorily.

"As Found" Tests

The tester must verify the meter number as the one on which the test is ordered. The reading of the register must be recorded and checked before removing the cover. An inspection of the general conditions around the meter should then be made. The seals on the meter should be examined and the wiring leading to the meter inspected to detect possible improper connections. When irregular conditions are found it is very important that no alterations be made in the meter or connections pending further investigation.

Before any connections are made, a test should be made with a lamp or voltmeter to determine if the meter base is alive to ground or in contact with any of the line wires. On grounded systems, a test should be made from the current coil terminal to ground, to assure that the current coil of the meter is not connected in the grounded leg.

The cover should be carefully removed, the necessary precautions being taken to prevent dirt and other foreign material from falling into the meter. The tester should then carefully check the register constant, register ratio and test constant.

A test for creep should be made with the house wires disconnected from the meter and before making the *as found* tests.

A meter is considered creeping when, with no load, the disk rotates at the rate of one revolution in five minutes or less.

If the meter creeps, the rate should be measured by timing the meter disk and the watts calculated according to the following:

$$\text{watts} = \frac{\text{rev} \times \text{watthour constant} \times 3600}{\text{seconds}}$$

If it is considered necessary to test the meter without interrupting service, the meter may be jumpered during the testing procedure.

Testing apparatus should be connected with the standard properly leveled, free from vibration, and placed where it will not be subject to injury.

Tests for *as found* percentage registration at the following loads are recommended:

Light load at 5 to 10 per cent of the current rating of the meter.

Full load at 60 to 150 per cent of the current rating of the meter.

The tester should report any conditions that will affect the proper performance of the meter.

The meter can then be adjusted in accordance with the directions given for its type.

"As Left" Tests

As left tests are made at the same load points as specified for *as found* tests.

The tester should then carefully disconnect the testing equipment and reconnect and seal the meter and service equipment. The final reading of the register must in all cases be carefully checked and recorded after the meter is sealed.

Before leaving the meter, the tester should see that it is operating, that the customer's circuit is complete, and that all connections are secure.

ADJUSTMENTS

The adjustments of a meter are the full-load, light-load, and lag adjustment. Most polyphase meters have an additional adjustment to obtain balance between elements. The lag and balance adjustments are generally made in the shop.

Full-Load Adjustment

This adjustment is effected in most meters by changing the position of the damping magnets or by varying the amount of flux passing through the disk. The change produced in the percentage registration is practically the same on all loads; that is, if the registration is 98 per cent at both full load and light load, shifting the full-load adjustment so as to increase the speed 2 per cent will make the meter correct at both loads.

Light-Load Adjustment

This adjustment is effected by varying the amount of friction compensating torque. The effect of this is inversely proportional to the load; that is, twice as much is required at 5 per cent as at 10 per cent load; one-tenth as much at full load as at 10 per cent load.

Generally, when a meter is found inaccurate, the cause is some condition in the meter which should be removed, rather than compensated for. In such cases the tester should locate the trouble, making no adjustments unless the meter is still inaccurate after going over all the parts and restoring them to proper condition.

Lag Adjustment

This adjustment is ordinarily made in the shop as a part of the routine test of all alternating-current meters for the reason that facilities for the test are readily available and the adjustment, once carefully made, will not ordinarily change in service.

The test to determine the lag or phase adjustment is generally made at fifty per cent power factor with rated current and voltage applied. Fifty per cent power factor is generally used because it can be readily obtained from a polyphase circuit without auxiliary equipment.

CREEP

Creep may occur either backward or forward. When load is removed, a meter will generally rotate for a part of a revolution before coming to rest. This is *not* creep. All observations for creep should be based upon at least one complete revolution.

Although only an unusually rapid rate of creeping will result in an appreciable registration, yet as a matter of principle, no meter in service should be allowed to remain creeping.

Causes of Creeping—The causes of creeping may be classified as follows:

(a) Incorrect compensation for friction.
(b) Vibration.
(c) Stray fields, either internal or external.
(d) Too high voltage, which has the same effect as over-compensation.
(e) The potential circuit being connected on the load side of the meter when the friction compensation has been adjusted with the potential circuit connected on the service side.
(f) Short circuits in current coils.
(g) Mechanical disarrangement of the electromagnetic circuit.

Leakage or grounding in the customer's circuit may cause a turning of the rotating element which may be mistaken for creeping.

In most induction meters, creeping is prevented by two holes or slots cut in the disk on opposite sides of the shaft. When either hole is near the pole of the potential coil, forces set up by the alternating field tend to hold the disk in this position.

If a short circuit is present in the current coils it will probably be difficult to stop creeping. The creeping is caused by currents being induced in the current coils by the potential magnetic flux. The coils should be properly insulated, or replaced by new ones.

BEARINGS

If bearings become defective they generally increase the friction and consequently cause the meter to run slow. The effect on percentage registration would be about ten times as great at 10% as at full load.

Top Bearing—The function of the top bearing is to act as a centering guide.

Excessive friction at this point may be caused by undue wear, corrosion or gumming. Such bearings should be either cleaned or replaced.

Lower Bearing—The lower bearing assembly ordinarily consists of a stationary sapphire jewel, with a pivot on the rotating element, or of two jewels with a ball between them. Excessive friction here may be caused by damaged jewels, worn or defective balls or pivots, or the presence of foreign material in the jewel.

Pivots and balls used with sapphire bearings should be replaced when replacing the bearing since, if the latter are rough, the former probably have been damaged. Where the jewel is still perfect, the pivot or ball may be worn.

Balls and pivots should not be touched with the fingers. Pivots should be inserted with a wrench provided for that purpose. Balls may be inserted into bearings by use of a ball dropping device.

Use of Oil—The lower pivot type bearing should be oiled by filling the bearing cup with oil recommended by the manufacturers. Care should be taken not to mix oils of different characteristics. Lower bearings of the ball type should never be oiled.

REGISTERS

The tester should inspect the register to detect any defects which may prevent its correct registration.

The worm or pinion on the shaft should be examined to see that it meshes properly with the register wheel which it drives. A slight amount of play is necessary to prevent excessive friction.

Where the pinion or worm is short, or where the worm is cut concave to match the curvature of the worm wheel, the height of the moving element should be set so that the center of the pinion or worm is level with that of the register wheel which it engages.

For cleaning the pinion or worm, a small stiff brush or a sharpened piece of soft wood may be used.

In some meters, the worm wheel is supported in a separate bracket attached to the meter frame in which case it is customary to actuate the register by means of a dog on the register engaging with a star wheel or second dog on the worm wheel shaft. It is important that these parts be in proper alignment.

All the gears on the register must be in mesh, and all dial pointers secure. Misplaced pointers should be re-set. The tester should record the position of the misplaced pointers. This condition may be an indication of an incorrect train ratio, i.e., one or more of the gears or pinions may have the wrong number of teeth.

CAUSES OF FRICTION

Friction may be caused by foreign matter, defective bearings, or improper alignment of parts interfering with the operation of the rotating element. Friction may also be caused by a meter being out of level.

Particles of iron or other magnetic material cause friction by clinging to the magnet pole-pieces and trailing on the disk. To remove magnetic particles from the magnets, a thin brass or bronze magnet cleaner can be used, but a magnet brush having long bristles is preferable.

DEFECTIVE CURRENT AND POTENTIAL COILS

A short-circuited turn in the current coil will reduce the effective turns, and consequently will lower the torque of the watthour meter and hence its speed at or near full load. Induction meters will generally creep when some of the turns are short-circuited and often will be fast on light load and slow on full load. Generally meters with this defect should be returned to the meter shop for new current coils. On three-wire meters the test can easily be made by checking the meter registration on each current coil separately.

A short circuit in the potential coils will change the torque of the watthour meter, hence its speed. A meter with this condition existing will be found *out of lag* and should be sent to the meter shop for repairs.

POLYPHASE WATTHOUR METERS

In general, all of the foregoing testing procedure applies to polyphase meters with the addition of several considerations made necessary by the polyphase meter construction and its application.

Shop Test for Independence of Elements

This is a test to determine the effect of one element upon the other. The procedure for this test and the acceptable limits are prescribed in the *Code for Electricity Meters.*

Shop Test for Balance of Elements

This test is made to determine that the calibration of the separate elements of the polyphase meter agree within certain limits under corresponding conditions of test. The adjustments for balance once having been made will not change, unless defects occur in the meter, such as changes in the electromagnetic circuits. The balance test is made by connecting all potential coils in parallel and applying full rated current of the meter at unity power factor to each current circuit one at a time, and checking calibration. When properly assembled and adjusted, the accuracies of the separate elements will agree within the required limits. The test should be repeated with full rated current at 50 per cent power factor, the accuracy limitations being in accordance with local requirements. For meters in which the light-load and lag adjustments are not entirely independent in their effect, the degree of unbalance of elements on light load will have a bearing on the accuracy performance of the meter.

If the accuracies are not within the required limits, adjustments may be made as follows:

By means of the torque-balancing adjustment of the separate elements on full load at unity power factor so as to conform to the established limits. This adjustment affects the accuracies at other loads approximately the same.

By means of the lag adjustment on the individual elements to conform to the established limits.

If all elements are not within the established limits, it will be necessary to repeat those checks and adjustments necessary to bring the accuracies within the limits.

A final check of calibration and adjustment may be made by connecting all potential coils in parallel and the current coils in series, and applying full rated current at unity power factor, and ten per cent of rated current at unity power factor.

Any polyphase meter, having been tested in the shop and adjusted for independence and balance of elements as outlined in the foregoing, may be tested in service with a portable standard watthour meter by connecting the potential coils in parallel and the current coils in series.

This method of making tests on polyphase meters is the one most generally used. Essentially the testing of any meter consists of comparing the speed of rotation of the meter with that of the standard, due consideration being given to their respective watthour constants. See diagrams, Figs. 9-19 to 9-26.

In testing polyphase watthour meters on other than unity power factor it is customary to test each element separately at a lagging power factor. A means for determining the phase sequence of the service supply is convenient in order to make proper connections.

When phase sequence has been determined by either of the methods described later, lag test at 50 per cent power factor is obtained as follows:

When sequence is 1-2-3 (see Fig. 9-9):

use potential from 1-2, current from 1-3
or potential from 2-3, current from 2-1
or potential from 3-1, current from 3-2

Similarly when sequence is 3-2-1:

use potential from 2-1, current from 2-3
or potential from 1-3, current from 1-2
or potential from 3-2, current from 3-1

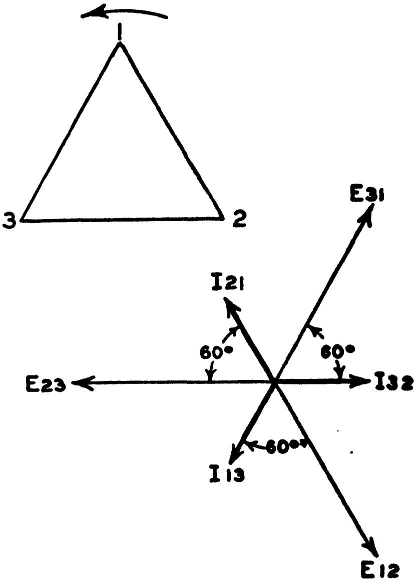


Fig. 9-9. Vector Relations of Voltages and Currents in Lag Test of Polyphase Watthour Meter Phase Sequence

Assuring Correct Connections

Since a polyphase watthour meter consists of two or more separate single-phase meter elements acting upon a common shaft, the separate elements of the meter are arranged and terminals provided so that the proper connections can be made. Connection diagrams are supplied by the manufacturers and if carefully followed correct connections should result.

In order that proper connections may readily be made at installation and traced at each test, it is common practice to use coded wire for installations having instrument transformers.

The connections for self-contained meters can usually be traced easily.

TESTING OF VARHOUR METERS

The method generally used for measuring kilovar-hours is by means of a watthour meter with potentials displaced ninety electrical degrees from those used in measuring kilowatthours.

There are various means by which potentials of the proper phase relation may be obtained. The two common methods are to use a phasing transformer with a standard watthour meter, or to use cross phase potentials. In either case watthour potentials may be applied to the potential coils and the meter tested as a watthour meter.

TESTING METERS INSTALLED WITH INSTRUMENT TRANSFORMERS

Meters installed with instrument transformers are generally tested as secondary meters in the same manner as a self-contained meter. It is important however, that the proper primary and secondary constants be considered.

In some cases it may be considered desirable to apply corrections for instrument transformers.

TESTING CONNECTIONS

Testing connections for various types of watthour meters are illustrated in Figs. 9-14 to 9-26.

AUXILIARY EQUIPMENT

Suitable equipment such as leads, jacks, clips, test lamps, tools, sequence indicators, loading devices, etc., should be provided in order that the work may be performed in an accurate and efficient manner. It is advisable that the company provide all equipment so that it will be standard and suited for the different kinds of testing. The equipment should be maintained in good condition. It is the duty of the supervisor to see that the equipment for each tester is kept intact and in good condition, and it is the duty of the tester to use the equipment carefully and to report any faults and defects which may develop.

Loading Methods

Two methods of current loading are in general use: resistance load and transformer (or phantom) load.

In the resistance loading method, Fig. 9-14, suitable resistance is connected in series with the current coils of the meter and standard, and is then connected across the line. The potential circuit of the meter is also connected to the line. This method is applicable to both direct-current and alternating-current testing, but is generally limited to low capacity meters.

In the transformer (phantom load) method, Fig. 9-15, the current coils of the meter and standard are placed in series with the secondary of a portable low-voltage transformer whose primary is connected across the line, suitable regulating resistance being placed in the secondary circuit. The meter potential circuit is connected across the line. This method is only applicable to alternating-current testing.

Where loading transformers are used, the power factor of the test circuit is less than unity. The lag in the current circuit is caused by the fact that the resistance of the current coils of the meter and standard is low as compared to their reactance. Under extreme conditions an unduly low power factor may be obtained. All such devices should be tested for power factor under working conditions. In a meter which is correctly lagged, the error introduced by a moderate phase displacement will be negligible. The use of apparatus likely to distort the wave form of the current should be avoided.

Customer's Load—The customer's load can be used for testing a meter but it is impractical for routine tests. It requires that the tester go into all parts of the premises, thereby causing annoyance to the customer. It also consumes an unreasonable amount of time and it is difficult to get the exact loading desired. It is, however, useful when it is desired to satisfy the customer as to the accuracy of the meter under operating conditions. It is not recommended except under special conditions.

Meter-Connection Devices

Meter-connection devices are installed on various equipment to expedite connections for testing in the field. In the case of bottom connected meters, the customer's load may be jumpered with flexible leads if test blocks have not been provided. A test jack is available for testing socket type meters. The jack is inserted between the meter and its socket and test connections made from it.

High-Voltage Connection and Test Devices

Meter installations having current and potential transformers require exceptional care and caution in their handling, not only that the accuracy of the transformers may be unimpaired, but also that the person making or changing connections may be safe from injury through contact with the high voltage developed by the accidental opening of the current transformer secondary. Connection blocks or test switches should be used. The practice of making temporary connections in the secondary of current transformers with wire jumpers is objectionable, since such connections are sometimes insecure, and also may impair the permanent wiring. There is also the possibility of leaving the temporary jumpers in place and shunting the current around the meter.

Various means are used to short-circuit current transformer secondaries in devices available for the purpose. Shorting is accomplished by inserting a plug or operating a switch, after which the desired testing connections can be made.

Leads and Terminals

For testing both in the shop and on the customer's premises, specially prepared test leads equipped with suitable terminals should be provided.

Periodic inspections of the test leads are recommended to insure against failure and to minimize the possibility of incorrect calibration of the meter. Particular attention should be paid to the potential switch to avoid excessive contact resistance which may affect meter calibration.

Phase-Sequence Indicators

Phase sequence may be determined by several methods, two of which are outlined below. Choice of the method depends upon the condition under which the tests are to be made and the equipment available.

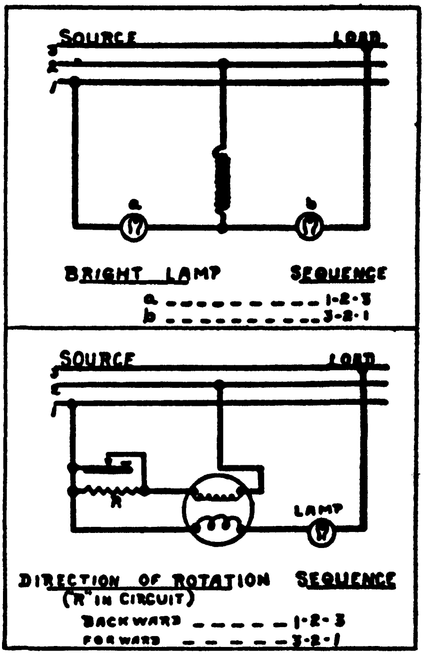


Fig. 9-10. Methods of Obtaining Phase Sequence

A simple phase-sequence indicator can be made by means of two identical lamps connected with a highly inductive reactance similar to a watthour meter potential coil. Such a device can be assembled in compact form by the use of tubular lamps and a small perforated metal case. Phase sequence is determined by unequal brilliance of the lamps. See Fig. 9-10. There are also available a number of commercial mechanical indicators.

Another method frequently used

consists of a non-inductive resistor (3000-5000 ohms) connected in series with the potential circuit of a watthour meter (or standard), the current coil being connected to another phase. This method is the most convenient in routine testing of polyphase meters. If the meter is connected so that the current in the series circuit lags the current in the potential circuit, introduction of the resistance R will cause the meter to run considerably slower, or reverse in direction. If the meter is connected for leading current, the speed of rotation with resistance R cut in will be increased, but still forward in direction. See Fig. 9-10. A suitable non-inductive load may be used in the current circuit.

REGISTER TESTING AND CHECKING

An important part of a watthour meter test consists of determining whether the watthour constant, register ratio, gear ratio and register constant are correct and also bear the correct relation to each other.

The correct watthour constant K_h for any particular size and type of meter can be found from the tables in Sections 13 to 16, inclusive. In order to check that a meter actually has the correct watthour constant, a test of the meter by any one of the methods previously described may be made.

The register ratio R_r may be determined by counting the number of revolutions of the first gear staff of the register which are required for one revolution of the first dial pointer. It is generally checked, however, by comparison with a register of known ratio. In the first method it is not necessary to take a complete revolution of the first dial pointer, one-tenth of a revolution generally being sufficient. In the second method, the register to be checked may be engaged with a shaft which is driving a register of known ratio, or the registration of the meter under test may be compared with the registration of a meter with known constants.

In order to calculate the gear ratio R_g it is first necessary to determine the ratio of reduction between the shaft of the rotating element of the meter and the first gear staff of the register, this reduction being referred to as the shaft reduction R_s. If there is a worm drive on the rotating element of the meter, the shaft reduction is equal to:

$$\frac{\text{no. of teeth in first register gear}}{\text{pitch of worm on rotating element}}$$

If the driving means is a spur gear, instead of a worm, the shaft reduction is equal to:

$$\frac{\text{no. of teeth in first register gear}}{\text{no. of teeth in spur gear on rotating element}}$$

The gear ratio R_g is equal to the product of the shaft reduction R_s and the register ratio R_r. One revolution of the rotating element of the meter is equal to K_h watthours. The number of revolutions of the rotating element for one revolution of the first dial pointer is equal to the gear ratio R_g and therefore one revolution of the first dial pointer will represent:

$$K_h \times R_g \text{ watthours,}$$

$$\text{or } \frac{K_h \times R_g}{1000} \text{ kilowatthours}$$

The numerical value of one revolution of the first dial pointer of a standard register is 10; therefore, the register constant K_r for kilowatthours is:

$$K_r = \frac{K_h \times R_g}{10 \times 1000}$$

$$\text{and } R_g = \frac{K_r \times 10{,}000}{K_h}$$

With these relations established the value of any one of the factors under consideration can now be expressed in terms of the others.

Let K_h = watthour constant*
R_r = register ratio
R_s = shaft reduction
R_g = gear ratio
K_r = register constant

* Primary watthour constant for meters with instrument transformers.

Then

$$R_g = R_r \times R_s$$

$$K_h = \frac{K_r \times 10{,}000}{R_r \times R_s} = \frac{K_r \times 10{,}000}{R_g}$$

$$R_r = \frac{K_r \times 10{,}000}{K_h \times R_s}$$

$$R_s = \frac{K_r \times 10{,}000}{K_h \times R_r}$$

$$K_r = \frac{K_h \times R_r \times R_s}{10{,}000} = \frac{K_h \times R_g}{10{,}000}$$

For example, assume that the following data are given for a meter and it is desired to verify the correctness of the register constant:

$$K_r = 1$$

$$R_r = 66\ 2/3$$

$$K_h = 1.5$$

$$R_s = 100$$

$$K_r = \frac{K_h \times R_r \times R_s}{10{,}000}$$

$$= \frac{1.5 \times 66\ 2/3 \times 100}{10{,}000}$$

$$= 1$$

The register constant of 1, given in the data, proves to be correct.

In selecting a register of proper ratio for installation on a meter, the formula

$$R_r = \frac{K_r \times 10{,}000}{K_h \times R_s}$$

may be used, but it will be noted that the value for R_r thus obtained depends upon the value selected for the register constant K_r. Recommended standard register constants for most sizes of meters are shown in Section 17, these register constants having been selected with a view towards preventing the complete turnover of a register within a billing period. For any size of meter not shown in the table in Section 17, it is recommended that a register constant be selected which will provide this safeguard against turnover.

In certain cases the register ratio available does not exactly correspond to the register ratio computed as being required. In such cases the meter watthour constant may be changed within narrow limits to correspond to the register ratio available by adjusting the speed of the meter to correspond to the required watthour constant.

For example, it may be desired to select a register for a 2½ ampere, 240 volt, three-phase type V-3 General Electric Company meter used in connection with two 300/5 ampere instrument current transformers.

Then $K_h = 1.2 \times 300/5$

$$= 1.2 \times 60$$

$$= 72$$

selected $K_r = 10$

$$R_s = 100$$

and $R_r = \dfrac{K_r \times 10{,}000}{K_h \times R_s}$

$$= \frac{10 \times 10{,}000}{72 \times 100}$$

$$= 13\ 8/9$$

The nearest register ratio available to 13 8/9 might be 13 1/3. By solving for K_h, using the register ratio of 13 1/3, we get:

$$K_h = \frac{K_r \times 10{,}000}{R_r \times R_s}$$

$$= \frac{10 \times 10{,}000}{13\,1/3 \times 100}$$

$$= 75$$

The meter must then be adjusted for a primary watthour constant of 75 or a secondary watthour constant of 1.25, which is obtained by dividing the primary watthour constant by the ratio of the current transformers.

Fig. 9-11 illustrates a mechanical register checking device for comparison of registers against a master ratio indicator. Any type and make may be checked by providing the required mounting facilities and correct gearing. The device is operated by a small air

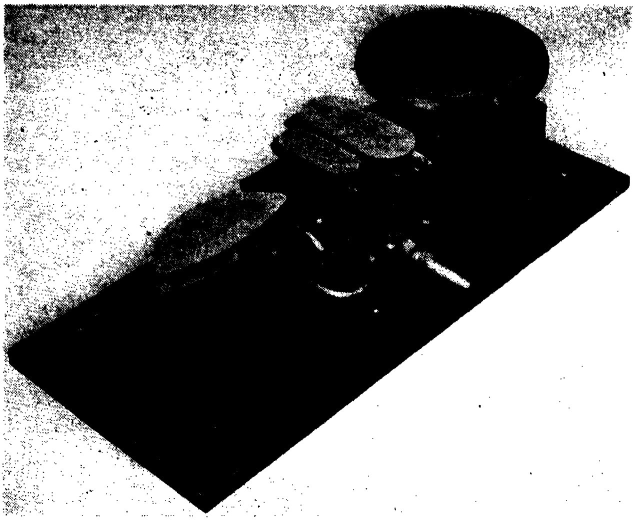


Fig. 9-11. Register Ratio Checking Device, air operated

turbine which permits flexible speed and reversible operation. The master dial is set at zero and the register or registers to be checked mounted in position. The lowest ratio is checked first by operating the device until the first dial pointer of the register makes one complete revolution. The register ratio is then read directly from the master dial. The register of the next

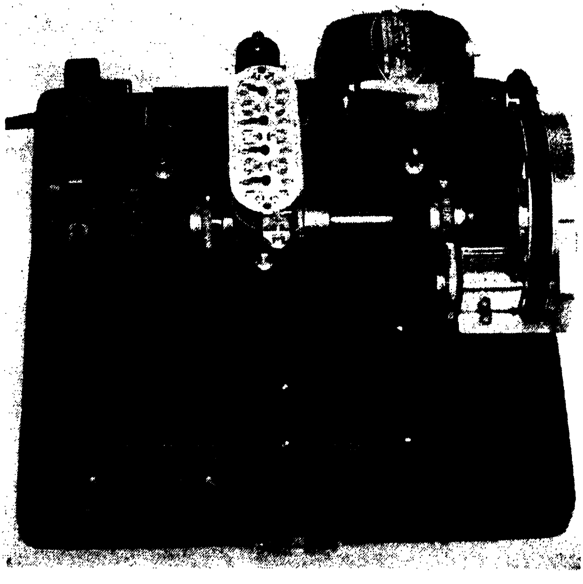


Fig. 9-12. Register Ratio Checking Device, motor operated

lowest ratio is then checked by continuing the run until its first dial pointer has made one complete revolution and the master dial read, etc.

A motor driven register checker which may be used for checking any type and make of register is illustrated in Fig. 9-12.

An alternative method of register checking is by the use of a time-run test in which meters are connected in series with standard meters having known constants and are operated for sufficient periods of time to verify their constants.

This method has some advantage over the use of register checking devices in that the complete performance of the meter is verified as well as establishing the correctness of constants. The disadvantages of this method are the increased time, equipment and space required. A representative "time run" test board is illustrated in Fig. 9-13.

TESTING DEMAND METERS

Demand Registers

The demand register is a device primarily intended for mounting on a watthour meter in place of a conventional register. It records kilowatt-hours by conventional dials on the register face identical to those used on watthour meter registers and, in addition, provides an indication of the integrated maximum demand. The maximum demand may be indicated by a pointer which moves over a demand scale placed on the register face, or may be indicated by dials similar to the kilowatthour dials. Meters so equipped with demand registers are called watthour demand meters and are identical with corresponding types of watthour meters except for the registers and covers.

The demand mechanism will introduce a small additional friction in the register which is automatically compensated for when the meter is adjusted.

Fig. 9-13. Time Run Test Board

The register timing motor may have a small magnetic interference effect upon one or more of the elements, which will slightly increase or decrease the meter torque, depending upon whether it is connected to add to, or subtract from the potential coil flux. This effect on meter calibration is constant, and like the increased friction effect, is automatically compensated for when the meter is adjusted. The motor should be connected in parallel with the potential coil of that meter element to which the interference is the greatest. Once established, the polarity of these connections should not be reversed.

Demand meter registers vary widely in their construction and design, as may be seen from the figures shown in Sections 13 to 16. The scales vary in pointer sweep from 180° to 340° and pointer reset devices of various kinds are in use.

The check of register ratio, etc., as to the kilowatthour portion of the register is made exactly as described previously for watthour registers. The proper indication of kilowatt demand may be determined, knowing the demand interval.

For a 15 minute demand interval—
1 kwhr produces a reading of 4 kw

For a 30 minute demand interval—
1 kwhr produces a reading of 2 kw

For a 60 minute demand interval—
1 kwhr produces a reading of 1 kw

It is of major importance that the demand portion of the register be checked in the shop and periodically in the field.

Checking Clutch and Pointer Tension—The correct operation of the demand register depends to a great extent upon the correct setting of the clutch and pointer tension. Devices for checking pointer and clutch tension may be obtained from the several manufacturers, and should be a part of the shop equipment.

Checking Timing Motors — Timing motors of certain types may be checked by the stroboscopic method, using a neon lamp or similar arrangement to check the speed of the motor disk or armature. Other types may be checked by timing the low-speed reduction gear. An over-all check of demand interval can be made by determining the time between successive demand interval resets.

Since the speed of the motor determines the length of the demand interval, incorrect motor speed will result in incorrect demand registration.

Over-All Test—With the demand register in place on the meter, an overall test of the accuracy of demand indication may be made by loading the meter for a complete demand interval with a portable standard watthour meter in series.

The true watts which should be indicated by the demand register can be determined as follows:

$$\text{true watts} = \frac{\text{watthours recorded by standard} \times 60}{\text{demand interval (minutes)}}$$

Manual Test—A manual test of a demand register may be made by rotating the timing gears through a reset operation. This operation will set the pointer pusher to zero and allow the pointer to be set on zero. After this operation, rotate the first gear of the demand register a given number of revolutions. The reading on the demand scale should correspond to some definite value obtained from the equation:

$$\text{kw registration} = \frac{K_h \times R_s \times \text{no. of rev of first gear} \times 60}{K_r \times 1000 \times \text{demand interval (minutes)}}$$

Where K_h = watthour constant of watthour meter with which demand register is used.
R_s = shaft reduction
K_r = register constant applying to the demand indication.

Mechanical Test—Testing devices are available or can be made by which the first gear of the demand register is driven manually or by a synchronous motor at one of several speeds representing various percentage loads on a watthour meter. In the manual device, the timing train is usually advanced at a higher than normal rate of speed so that several complete checks of gearing at various scale points can be made in a very short time. With the automatic drive, the demand register is usually allowed to run for several full demand intervals.

Contact-Operated Demand Meters

Contact-operated demand meters operate by impulses produced by a contact device within the watthour meter. These impulses actuate a separate demand meter to produce in the various types an indicating or a cumulative reading, a graphic record, or they may print on a tape a number proportional to the demand of each interval. Demand meters of these various types and their principles of operation are described in Sections 14, 15 and 16.

Contact devices may be of the two-wire or the three-wire type depending on the principle of operation of the demand meter. Typical contact devices operating from the meter shaft are shown in Fig. 14-41 and 16-29. Register mounted types are shown in Fig. 16-27 and 16-28. The determination of demand contact ratios and demand constants is covered under the heading *Kilowatt Constant* in Section 14, and under *Demand Constant* in Section 16. The formulas serve for the initial determination of the constant on new installations and for checking the correctness of the demand contact device in the field. It is important that contact devices be handled carefully, since any derangement of the parts may result in faulty operation. Contact devices introduce a small additional friction and it is important that final adjustments of the meter, particularly at light load, be made with the contact device in place.

The general principles that apply to the checking of demand registers apply also to separate demand meters, modified in accordance with the design of the individual demand meters.

Shop Tests — In preparing demand meters for service it is important that both the electrical element and the mechanical operation be carefully checked. With synchronous motor drive, generally used wherever possible, timing elements are relatively free of trouble. However, they should be checked for the correct demand interval. Also, incorrect motor speed will result in incorrect demand registration. Clock mechanisms, either manual or motor-wound, should be adjusted for correct timing. When the various elements of the demand meter have been inspected and adjusted, the demand meter should be set up in the shop to operate from a definite number of contacts per interval, from a meter set up for the purpose, or with the meter with which the demand meter will be used in service. Preferably this test should be run for at least 24 hours. In addition to checking the value of maximum demand, the kilowatthour registration during the test should be checked with that recorded by the demand meter. Most types of demand meters have dials or cyclometers for this purpose. Where these are not provided, the sum of the individual kw demand readings should equal the kilowatthours during the test for hourly demand; it will be twice the kilowatthours for 30-minute demand and four times the kilowatthours for 15-minute demand. Any defects indicated by this test should be corrected before the demand meter is placed in service.

Service Tests—Routine tests in the field are preferably made in conjunction with tests on the watthour meter. Ordinarily this will include a check of the electrical and mechanical operation of the demand meter, an inspection of the contacts in the meter, and a check to determine that the demand meter resets properly. The demand interval, namely the time between resetting operations of the demand meter, may be checked by means of a watch while the other tests are in progress, provided that the supply to the timing motor is not interrupted. Contact devices in meters should be replaced if their condition requires excessive surface dressing.

Over-All Test—With the demand meter connected to the watthour meter an overall test of the accuracy of the meter and demand meter may be made by testing the meter for a complete demand interval with a portable standard watthour meter. The demand interval should be timed at the same time. The method is described under *Demand Registers*.

Maintenance by Replacement—With a view to reducing maintenance of demand meters in the field it is sometimes feasible to inaugurate a periodic replacement program of parts that are known to wear. For example, some types of synchronous motor clocks are subject to failure after long and continuous service. A periodic replacement program will reduce failures that would otherwise result in loss of records. The same principle may be extended to apply to contact-operated demand meters generally. In this way the demand meters would be returned to the shop periodically for the replacement of all worn parts after which they would be equal to new and serve for new installations or replacements.

Totalizing Relays

The general principles applicable to contact-operated demand meters apply also to totalizing relays. In each case, the manufacturers' instruction sheets on the individual devices will be useful.

Graphic Watthour Demand Meters

Meters of this type, which include both a watthour meter and a strip-chart demand meter, are the RB and R-2 line of watthour meters, Fig. 16-20 and 16-21, and the DG-1, Fig. 14-27. In this group also is the RI watthour and recording kva demand meter, Fig. 16-22 and 16-23. The general principles of testing and maintenance apply also to these meters, and manufacturers' instruction books are useful for detailed procedure.

Thermal Watt Demand Meters

The thermal watt demand meter is available as a separate meter or as an integral part of a combination watthour thermal demand meter.

Testing thermal demand meters requires the application of load to the meters under test in series with some form of standardized watt measuring device. Such tests are preferably made in the meter shop. Practical considerations indicate that routine testing at one load of approximately 75% scale deflection at unity power factor accomplishes all that is necessary to assure a commercially accurate meter. Tests at light load or at lagging power factor are unnecessary except to check for design limitations. Before testing with load, potential must be applied for at least two hours and the zero setting adjusted. The interval of test should be approximately three times the demand interval for meters under test.

Test Methods—Two test methods are available in one of which the meter under test is connected in series with an indicating wattmeter and in the other in series with a standardized thermal demand meter. Where an indicating instrument is used it should have a five-ampere current element and a potential circuit tapped for both 120 and 240 volts. Such a standard is readily calibrated for determination of corrections; a feature is that it indicates at a glance the magnitude of load that is impressed on the meters under test. However, very close voltage regulation is necessary.

An inexpensive and reliable standardized thermal demand meter can be established by altering, adjusting and calibrating a service type thermal watt demand meter. A number of variously rated standards may be used or a single standard meter having a five-ampere current coil and a 240 volt potential coil may be used in combination with instrument transformers. The maximum demand pointer should be removed to minimize frictional load.

Standards should be calibrated, and adjusted where necessary, on a periodic schedule by comparison with a precision type indicating wattmeter.

Test Procedure—Figs. 9-27 and 9-28 show recommended testing arrangements. The thermal demand elements should be tested as follows:

1. Energize potential coils only, for not less than two hours. While the coils are still energized, and with maximum demand pointer up-scale, adjust pusher pointer to zero.
2. Adjust the maximum demand pointer for proper friction.
3. Load the meters for approximately 75% scale deflection for a period equal to at least three demand intervals. With the load held constant, adjust the pusher pointer to proper setting as shown by the standard meter.
4. All test runs should be made with covers in place; after adjustment the covers should be in place for at least 15 minutes before observing results. Specially drilled test covers are available whereby cover removal is made unnecessary.

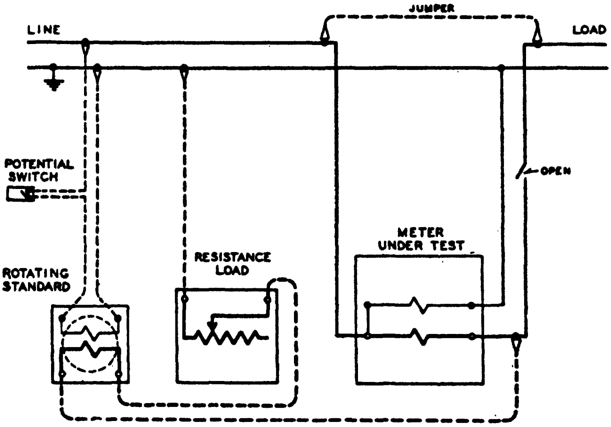


Fig. 9-14. Testing Connection for a 2-Wire Meter Using a Resistance Load

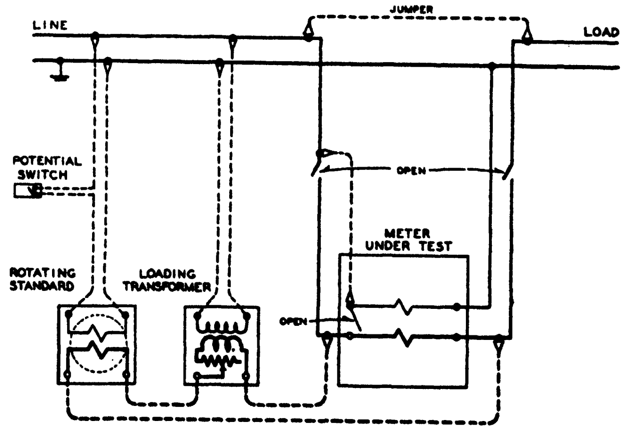


Fig. 9-15. Testing Connections for a 2-Wire Meter Using a Loading Transformer

Line side of meter may be left connected to service and potential jumper omitted. With such connections secondary of loading transformer and current coil of standard will be at line potential.

Some of the possible causes of inaccuracy are:

1. Loose electrical connections between potential transformers, heaters, shunts and terminals.
2. Loose pointers.
3. Friction due to distortion of bimetallic springs.
4. Defective or open shunts.
5. Defective adjustment springs.
6. Open potential coils, transformers.

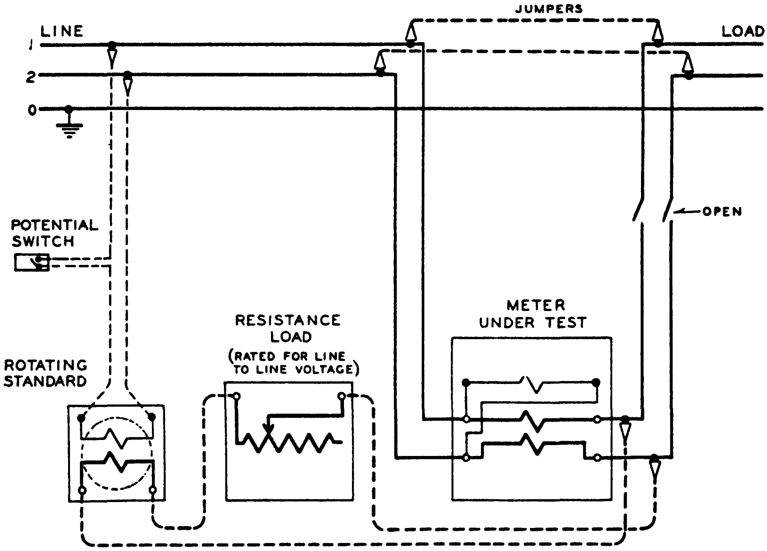


Fig. 9-16. Testing Connections for a 3-Wire, Single-phase Meter Using a Resistance Load on Line-to-Line Voltage

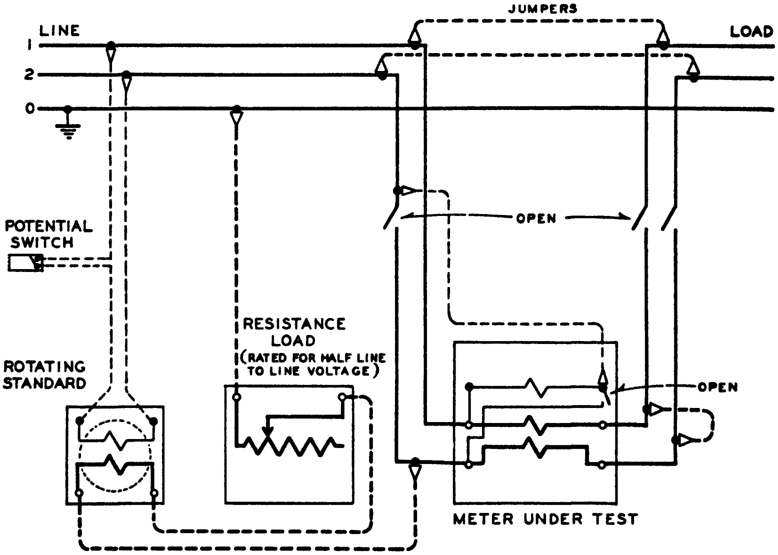


Fig. 9-17. Testing Connections for a 3-Wire, Single-phase Meter Using a Resistance Load Rated at Half-line Voltage (i.e. 120-volt Resistance Load to Test a 240-volt Meter)

Resetting—When resetting the maximum demand pointer do not move the pusher pointer down scale more than two main divisions. Release the reset mechanism slowly.

If undue force is applied against the pusher pointer, it is possible to bend it or slip the pointer on the shaft, thus causing a down-scale error thereafter.

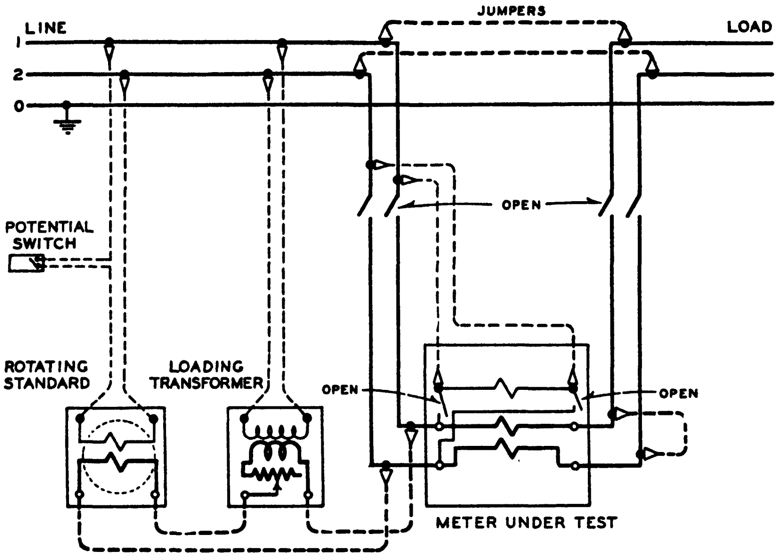


Fig. 9-18. Testing Connections for a 3-Wire, Single-phase Meter Using a Loading Transformer

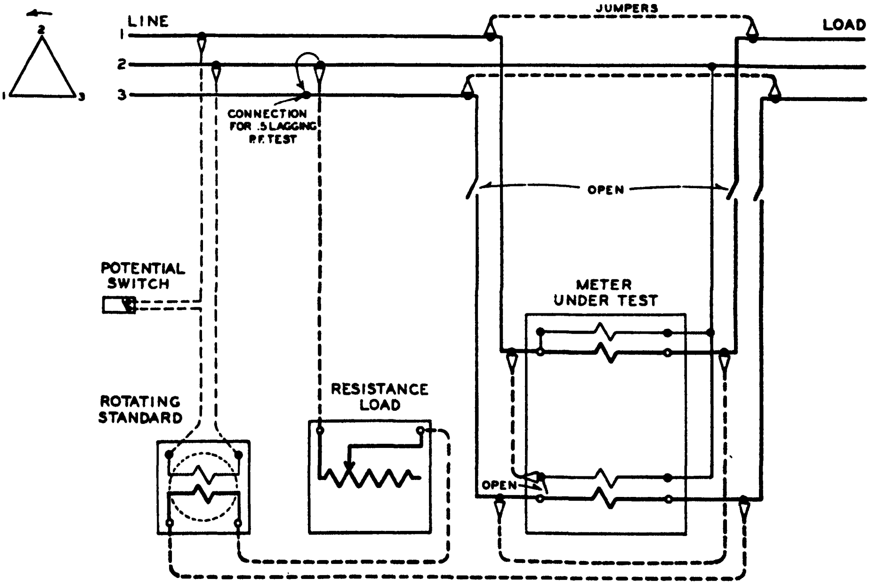


Fig. 9-19. Testing Connections for a 2-Element, 3-Wire Meter Using a Resistance Load (Current coils connected in series and potential coils in parallel). *To test for balance of elements, test each element separately*

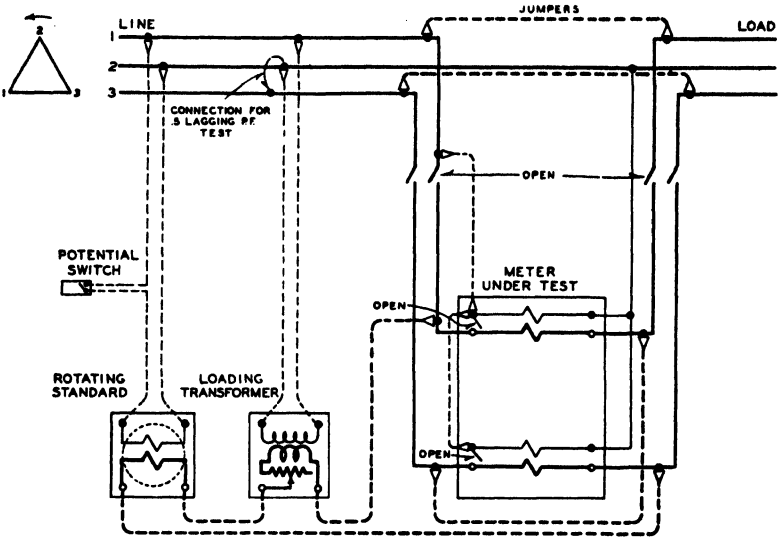


Fig. 9-20. Testing Connections for a 2-Element, 3-Wire Meter Using Loading Transformer (Current coils connected in series and potential coils in parallel) *To test for balance of elements, test each element separately. Line 1 may be left connected and potential jumper to line omitted*

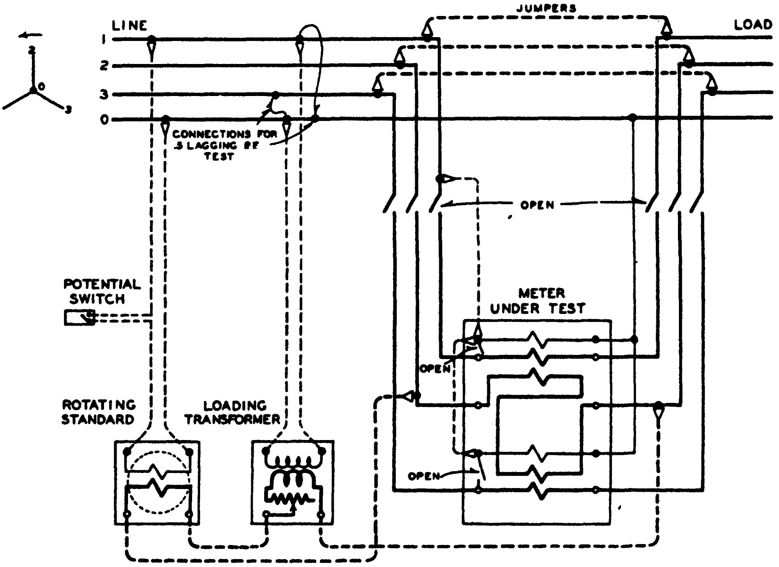


Fig. 9-21. Testing Connections for a 2-Element, 3-Phase, 4-Wire, Wye Meter Using the Split Current Coil Only

This is equivalent to a current coil in each element connected in series. Connections shown for a loading transformer; a resistance load may be used in a manner similar to that shown in Fig. 9-19, for a 3-Phase, 3-Wire Meter. Note: Windings of split current coil have reversed polarity.

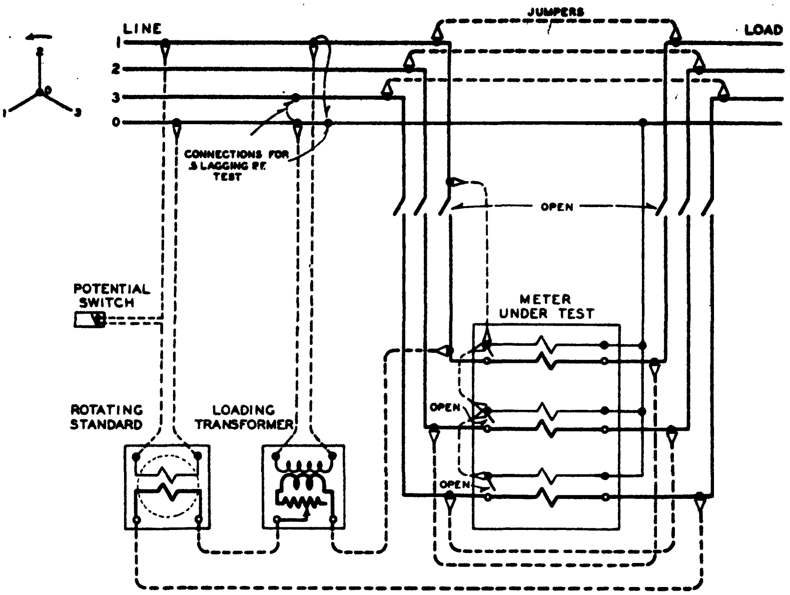


Fig. 9-22. Testing Connections for a 3-Element, 3-Phase, 4-Wire Wye Meter Using a Loading Transformer (Potential coils connected in parallel and current coils in series). *To test for balance of elements, test each element separately. May also be tested with a resistance load*

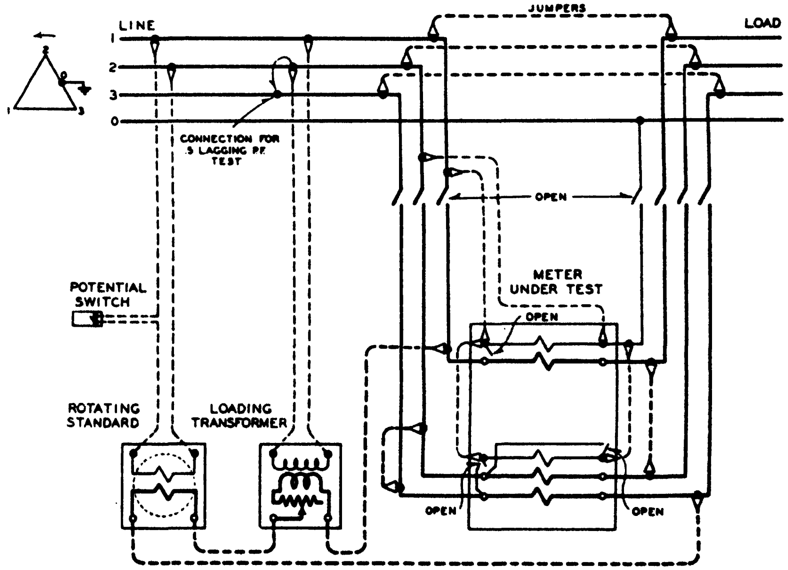
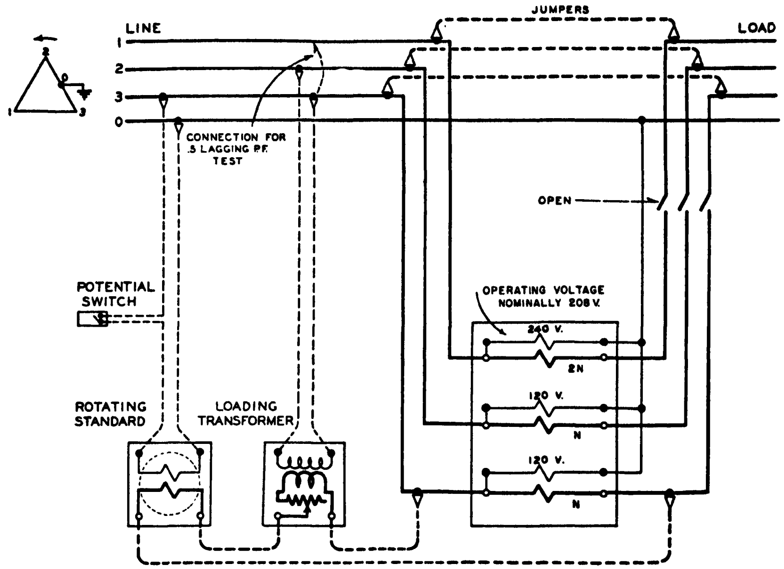


Fig. 9-23. Testing Connections for a 2-Element, 3-Phase, 4-Wire, Delta Meter Using Loading Transformer



NOTE:
WIRING CONNECTIONS SHOWN FOR TESTING A SINGLE ELEMENT - TO TEST OTHER ELEMENTS IT IS NECESSARY TO CHANGE PHASE CONNECTIONS TO LOADING TRANS. AND ROTATING STANDARD.
METER MAY ALSO BE TESTED WITH CURRENT COILS IN SERIES IF PROPER ACCOUNT IS TAKEN OF THE INEQUALITY OF ELEMENTS.

Fig. 9-24. Testing Connections for a 3-Element, 3-Phase, 4-Wire, Delta Meter Using a Loading Transformer

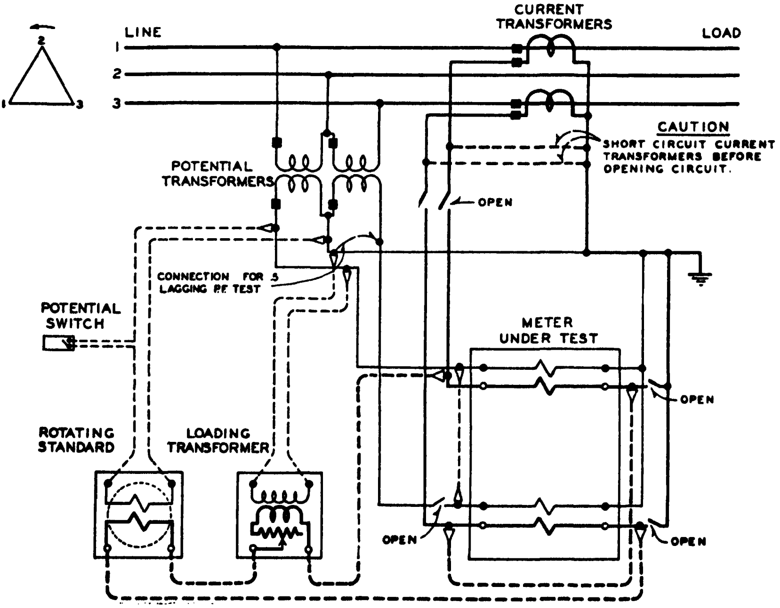


Fig. 9-25. Testing Connections for a 2-Element, 3-Phase, 3-Wire Meter With Instrument Transformers

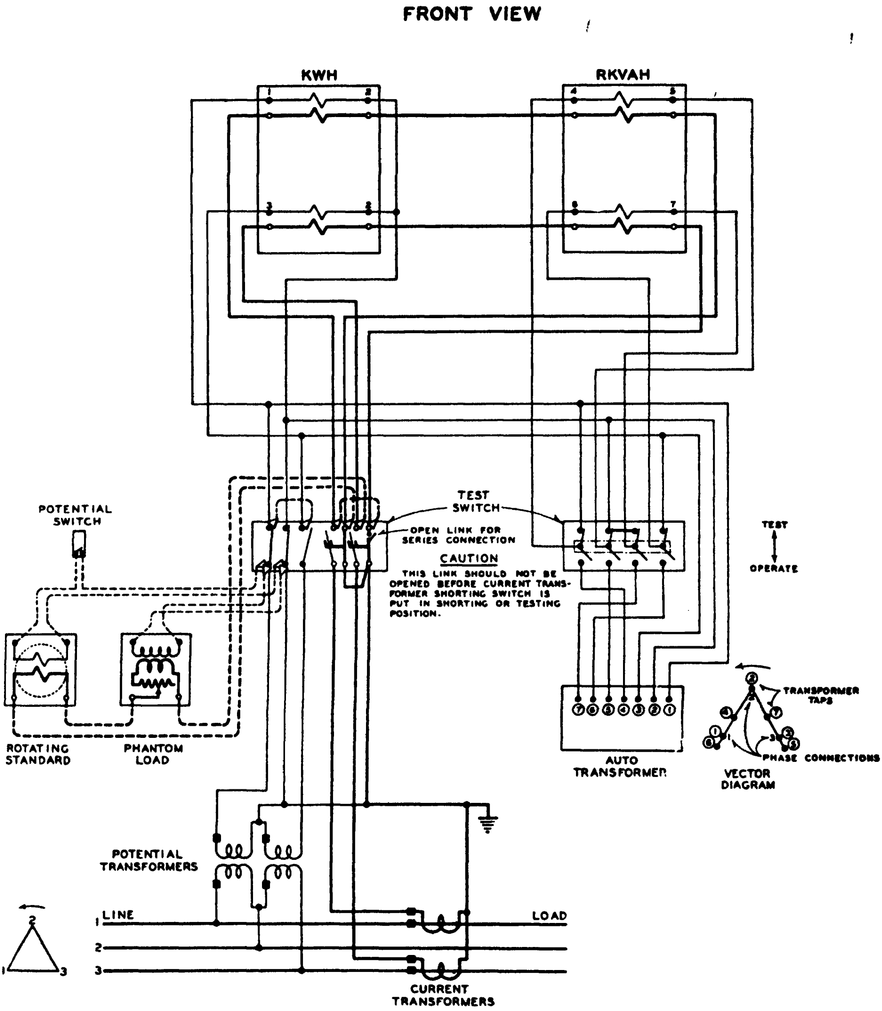


Fig. 9-26. Testing Connections for 3-Phase, 3-Wire Meter Installation With Typical Test Switches

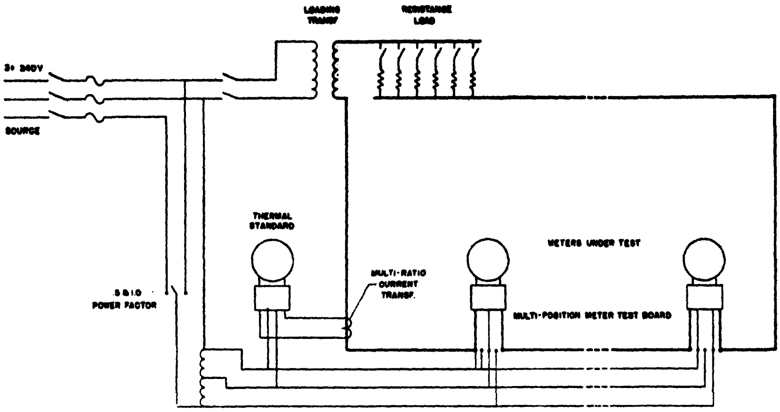


Fig. 9-27. Simplified Circuit For Thermal Demand Meters

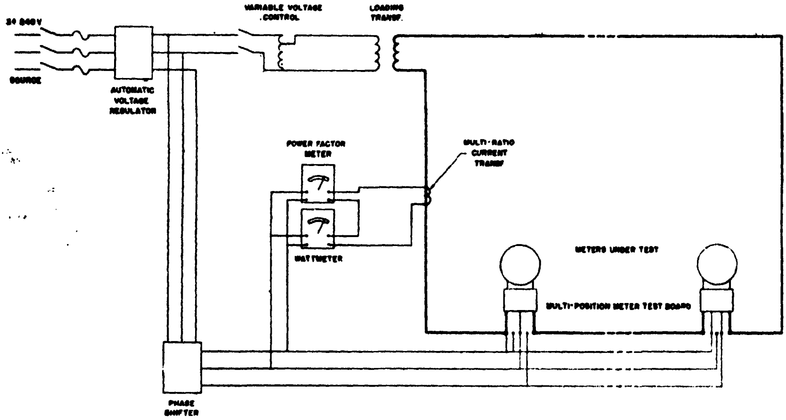


Fig. 9-28. Schematic Diagram of Demand Meter Test Facilities

SECTION 10

METER READING

Observing and recording the indexes of meters, while a routine operation, is one of major importance, since the purpose is to determine the quantities to be billed. It is important, therefore, that meter readers be carefully selected and properly trained.

Meter reading should be carried on under a carefully planned program by employees having the natural attributes of friendliness, courtesy and good appearance. They should be taught the fundamentals of customer relations and should be acquainted with various types of instrument dials in use by the company. A clear understanding of the terms and quantities involved in billing is very important. Therefore, meter readers should know the general meaning of terms such as kilowatthours, kilowatts, constants, demand, horsepower and power factor. Any training program should include a plan to familiarize meter readers with all new metering equipment or changes in meters or installations.

Upon entering a customer's premises a reader should announce himself courteously and produce proper credentials and identification whenever requested. To prevent undue annoyance to customers when new men are assigned to a route, every meter reading sheet should bear notations showing means of access, location of keys, location of meters, and notes of any unusual conditions.

Hazards which should be guarded against and which should be noted prominently on the reading sheet are defective sidewalk cellar doors, defective stairways, low beams, pits or sump holes, and dogs. In considering this last mentioned, and all too prevalent, hazard the article "Bow Wow, Mr. Meterman," may be found helpful. This was published in 1946 in the *Public Utilities Fortnightly* and was reprinted in the February 1946 *Edison Electric Institute Bulletin*. Reprints of the article are available.

A meter reader should be observant in detecting defective service equipment, hazardous conditions in customers' wiring or electrical equipment, evidence of overloaded meters, faulty meter operation, and cases of unmetered electric service.

Readings should be taken on a prearranged schedule to make billing periods as nearly equal as practicable. Meter numbers should be checked to make sure that readings are entered on the correct reading sheets. Entries should be clearly written in ink. Incorrect entries should be crossed out but not erased. Suitable explanations should be made of any unusual conditions.

HOW TO READ A WATTHOUR METER

There are two styles of kilowatthour meter register faces in general use. One has individual dial circles and the other has interlocking dial circles as shown in Figs. 10-1 and 10-2.

Most standard registers are provided with four dials but some standard registers are provided with five dials to avoid a multiplying constant of 10. Adjacent pointers rotate in opposite directions and are so geared for travel that the pointer on the right will make one complete revolution, while the one next to it on the left makes 1/10th of a revolution. When a pointer is between two figures, the smaller figure is the one to use as a part of the reading.

A watthour meter is read from right to left and all dials must be read. The right hand dial governs the one on its left in each instance. When the kilowatthour constant is 1, a complete revolution of the pointer on the right hand dial indicates 10 kilowatthours. The pointer on the dial next to the left indicates in one revolution 100 kilowatthours and so on. To read the dials, the procedure is like reading units, 10's, 100's and 1000's.

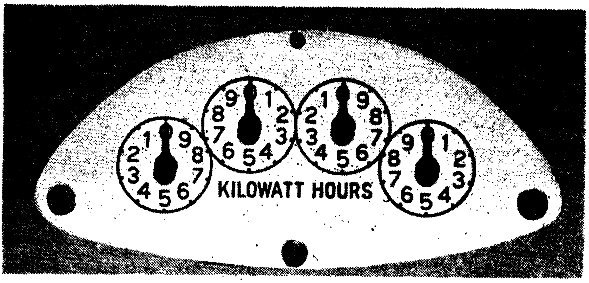


Fig. 10-1. Conventional 4-Pointer Watthour Dial

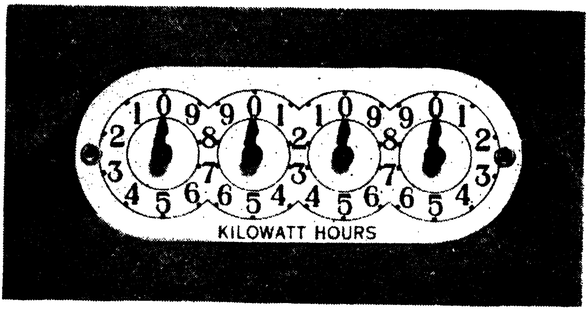


Fig. 10-2. Conventional 4-Pointer Watthour Dial With Overlapping Circles

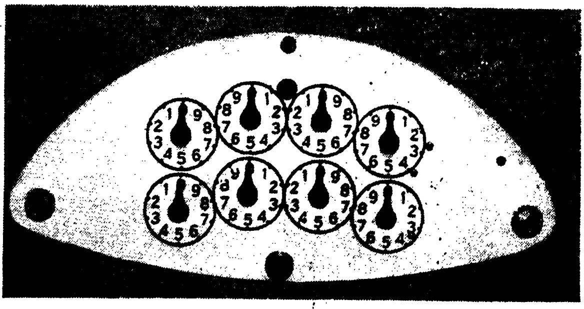


Fig. 10-3. One Type of Two-Rate Register

Each pointer must complete a revolution to advance the next pointer towards the left one division. When the angle of view or other reason causes doubt as to whether a pointer has reached or passed a numeral, reference should be made to the next pointer to the right, which, in all cases, must pass zero to cause the pointer in question to pass the numeral. A simple analogy can be made with a watch. When the hour hand is near 8 and the minute hand is at 11, it is not yet 8 o'clock, but is 7:55, and obviously it will not be 8 o'clock until the minute hand has completed its revolution.

To obtain the use in kilowatthours over a period it is necessary to subtract the previous reading from the present reading. When the kilowatthour constant is 1, the difference will be the number of kilowatthours used between the two readings. When the kilowatthour constant is other than 1, either the readings themselves prior to subtraction or the difference between the readings following subtraction must be multiplied by the given kilowatthour constant to obtain the kilowatthours used. Kilowatthour constants of 1 generally are not shown, but those of other than 1 are shown on the dial faces.

Double or two-rate registers employ two sets of dials and two complete register mechanisms which are automatically switched into gear with the moving element shaft at predetermined times, Fig. 10-3.

HOW TO READ A DEMAND METER

Demand readings are usually in terms of either kilowatts, kilovolt-amperes, or kilovars, the quantity measured being indicated on the dial face or the nameplate of the instrument. The demand device may be incorporated within a watthour meter, may be associated with a separate watthour meter, or may be independent of any watthour meter. In reading demand meters, it is essential that the proper relationship of associated equipment be shown on the records.

Demand readings may be either indicating or recording. Indicating demand readings usually are obtained by one of the following means:

1. A single sweephand type of pointer, in which case the position of the sweephand is read, and the pointer is then reset as far as the position of the pusher arm will permit.
2. A sweephand type of pointer plus a cumulative feature, in which case it is general practice to record the position of the sweephand, then to reset the sweephand to zero and record the reading of the cumulative device.
3. A sweephand type of pointer showing maximum demand, plus a sweephand type of pointer, the pusher pointer, showing current demand. In this case it is customary to record the position of the maximum pointer and then reset the maximum pointer only as far as the pusher pointer.
4. Dials of the pointer or cyclometer type showing cumulative readings, in which case the dials are advanced and a record is then made of the dial reading.

In reading a demand meter of the sweephand type, it is important that the reading be taken, as closely as practicable, from directly in front of the meter. This is to avoid errors in reading due to parallax.

Following the operation of a reset device or operating mechanism it is necessary that the device be sealed or locked, and that it remain so until the next reading.

Recording demand meters may be of either the curve-drawing or printing type. In either case it is generally the practice to remove the chart at the time of reading, to identify it with the meter upon which it was used, and to return the chart to the office for determination of demand.

Some demand meters are direct reading, having scales or charts so designed that the instrument has a constant of 1. In many cases, however, it will be necessary to multiply the indication by the constant shown on the meter to obtain the demand in the desired unit. When kilowatthours and kilowatt readings are obtained from the same meter, the multiplying constants for each may or may not be the same, so each should be verified before being used to determine the quantities to be billed.

Watthour Demand Register, Indicating Type—An indicating type of demand register, shown in Fig. 10-4, is provided with four kilowatthour dials and these are read in the manner previously described. The maximum demand is determined by the position of the pointer on the scale in a manner similar to reading a voltmeter. When the number of sub-divisions between the marked or numbered divisions is ten, the reading of the pointer is the

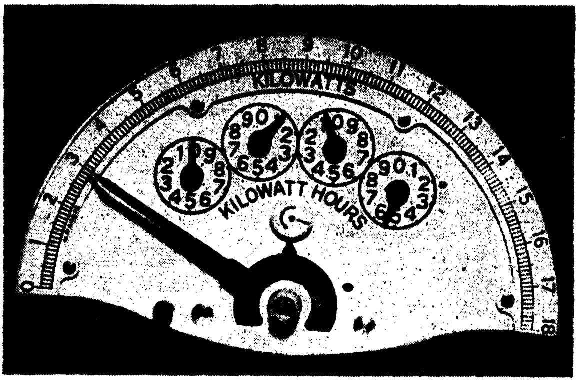


Fig. 10-4. Watthour Demand Register, Indicating Type

value of the marked divisions plus the value of the sub-divisions in tenths of the major divisions. The demand value shown in Fig. 10-4 is 3 kilowatts. If the pointer was two sub-divisions higher than shown, the reading would be 3.2 kilowatts.

Watthour Demand Register, Cumulative Type—Fig. 10-5 shows a cumulative type watthour demand register. This register has, in addition to four kilowatthour dials, four similar dials for registering maximum demand. These demand dials are read in the same manner as the kilowatthour dials. To obtain a reading of the maximum demand on this device it is necessary to operate a mechanism attached to the meter cover. The kilowatt demand for the billing period is then

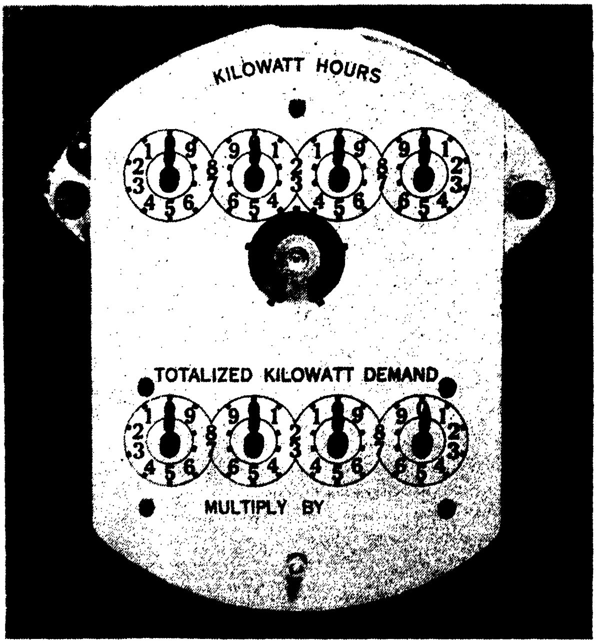


Fig. 10-5. Watthour Demand Register, Cumulative Type

Fig. 10-6. External Demand Meter, Indicating Type

automatically added to these dials. The dial pointers are stationary between indexing periods. Some types have cyclometer indicators in place of the demand dials.

External Demand Meter, Indicating Type—This type, Fig. 10-6, is separate from, but electrically operated by impulses from, one or more watthour meters. This meter is read in the same manner as the indicating demand register, in Fig. 10-4. The external demand meter may also be of the cumulative type, in which case the meter is also provided with four kilowatthour dials similar to the register shown in Fig. 10-5.

External Demand Meter, Chart Type—A typical meter, Fig. 10-7, records upon a circular chart, Fig. 10-8, the kilowatt demand for each demand interval and as the chart is driven by a time mechanism the time of day and the day of the week are indicated. Some of these have inverted charts with zero at the outer edge of the chart. The maximum kilowatt demand is obtained by finding the highest value recorded for the demand interval, which may be 5, 15, 30 or 60 minutes, depending upon the rate established. This determination is generally made for a monthly billing period. When the highest kilowatt value is found the time of day and the day of the week in which it occurred can be determined and stated for billing purposes.

Combined Watthour and Demand Meter, Chart Type—In this type of meter, Fig. 10-9, the demand device is mounted within the same enclosure with the watthour meter and mechan-

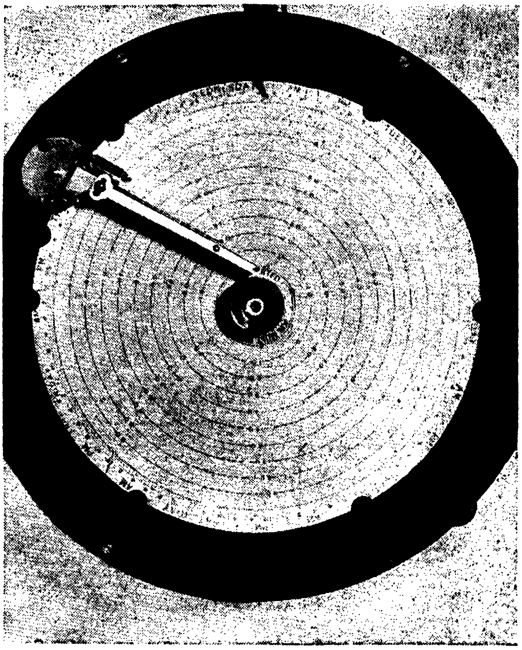


Fig. 10-7. External Demand Meter, Chart Type

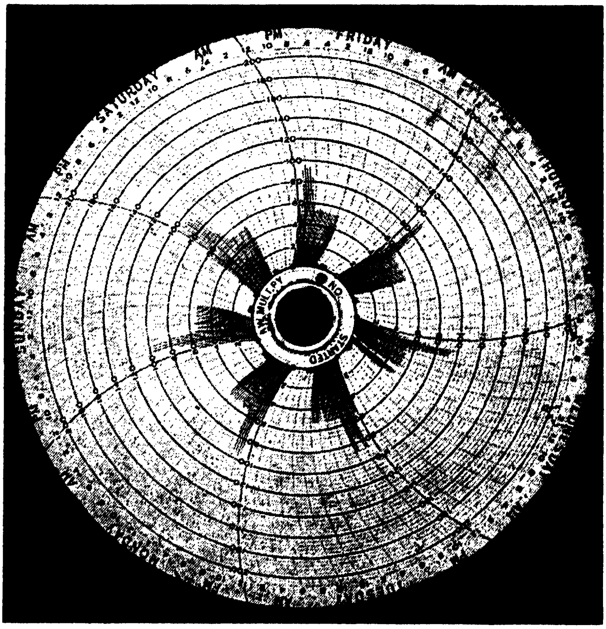


Fig. 10-8. Circular Chart Record

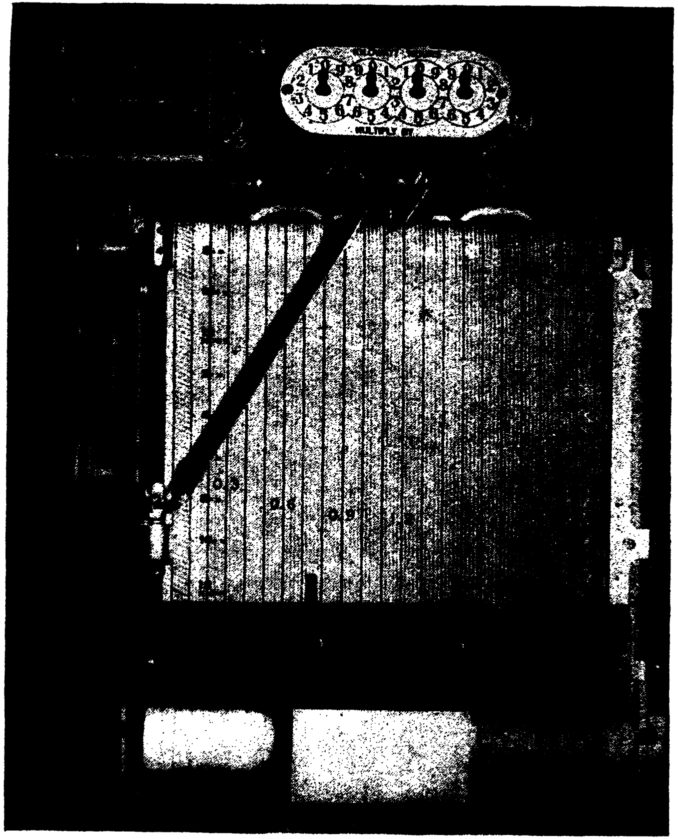


Fig. 10-9. Watthour Demand Meter, Chart Type

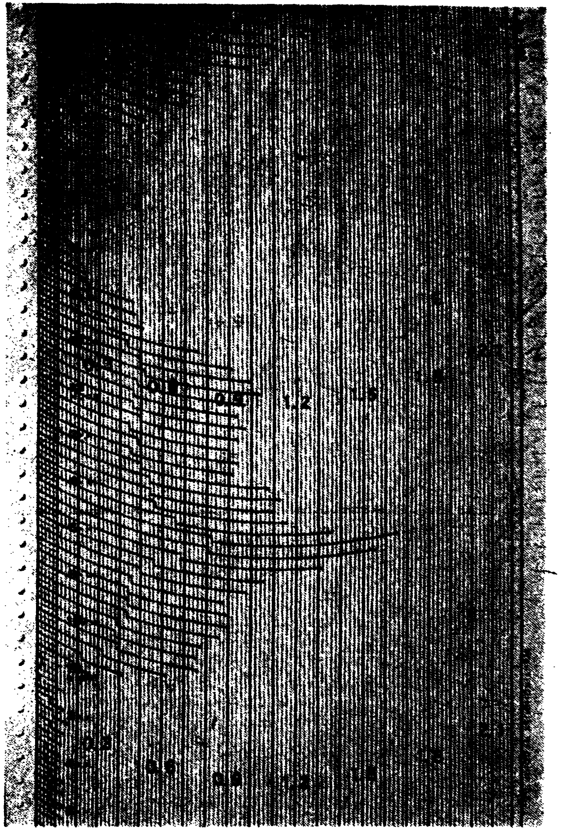


Fig. 10-10. Rectangular Chart Record

ically operated by the watthour meter. A strip type chart, Fig. 10-10, is used, which generally covers a period of one month. The determination of kilowatt demand is the same as for the circular chart type.

Demand Meter, Printing Type—This type of meter, Fig. 10-11, is electrically operated by one or more watthour meters, and prints the units of demand in type figures upon a paper strip, Fig. 10-12. It is commonly known as a printometer. The value printed is that for the demand interval of 5, 15, 30 or 60 minutes depending upon the rate established. The paper strip has printed on its margin the hourly time. A timing mechanism controls the printing mechanism and advances the paper strip after each printing operation. An indicator of maximum demand is provided at the lower right of the device and indicates the highest value that should be found on the printed paper strip.

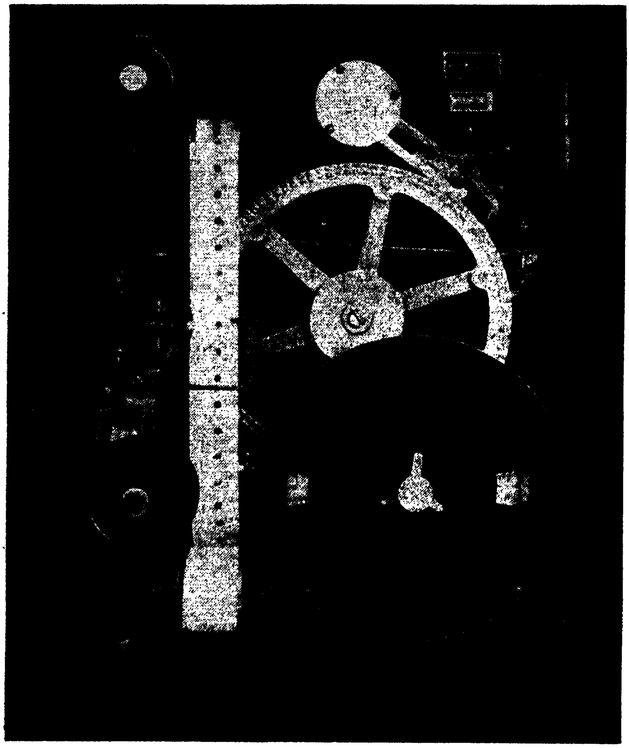


Fig. 10-11. Printing Type Demand Meter

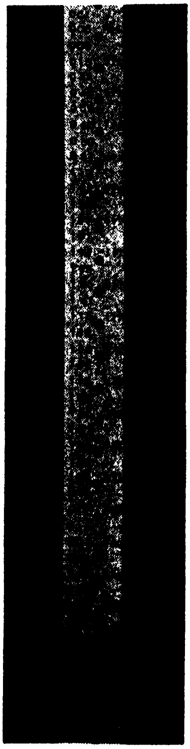


Fig. 10-12. Tape Record

SECTION 11

THE METER SHOP

The scope of the meter shop, while primarily covering work associated with customer metering, very often is extended to include various items of laboratory testing. A definite line of demarcation between the meter shop and laboratory cannot be established here. This section is, therefore, intended to cover the work usually found necessary in the meter department, but where laboratories are also maintained it is necessary to divide the work depending on local conditions.

The meter shop should be conveniently located with respect to the territory served. Ample space should be provided for the efficient and effective performance of all required operations not only inside the building housing the department but also in conveniently located parking space and garages for the department automobiles and trucks.

The building space provided for the department should be clean, well lighted and ventilated, and of good appearance. From the standpoint of the work performed, the area should be as free as possible from dust and wide variations in temperature, and even where ample daylight normally exists, supplemental and complete electric lighting should be installed to provide at least 20-foot-candles intensity on all working surfaces.

The area provided should be divided into sections for the clerical and office force, for routine meter maintenance, storage, and for standardization work. These areas should be further subdivided so that similar functions are grouped together but separated from dissimilar functions. Fig. 11-1 shows a typical meter test room and Fig. 11-2 a meter repair and store room.

Every meter department must be adequately equipped with instruments and testing equipment to perform all required functions. A poorly equipped department cannot operate efficiently or effectively. It is also of prime importance that the equipment provided be set up so as to be continuously available for use and so that preliminary test set-up time will be minimized.

POWER SOURCES

Alternating-current supply for the operation of testing equipment should be reserved solely for this purpose. Individual transformer banks to supply the required voltages, phases and capacity are recommended, and they in turn should be supplied from a well-regulated and reliable primary circuit whose voltage is not subjected to fluctuations or rapid variations. The transformers should be of sufficient capacity to avoid voltage regulation difficulties.

Usually, even these precautions are not entirely sufficient to result in a proper supply suitable for standardization and certain instrument work. Motor-generator sets or properly designed electronic-controlled voltage regulators may be required to provide a suitable supply. Synchronous-motor-driven generators are preferable if the frequency of the supply is comparatively uniform as in large interconnected systems; otherwise, double conversion may be necessary; that is, an a-c to d-c machine driving a d-c to a-c machine. In this latter case the machines should be physically large enough or provided with sufficient inertia and momentum to give proper regulation. The second a-c machine or alternator should not be smaller than 15-kva rating and as much larger as practicable in order to avoid voltage regulation difficulties. For the usual calibration work, a sine wave generator is not essential, and a good commercial wave form should be all that is required. However, a sine wave source may be necessary for special work.

A constant-voltage d-c supply is re-

Fig. 11-1. Typical Meter Test Room

Fig. 11-2. Typical Meter Repair and Storeroom

quired for the operation of potentiometers, resistance bridges and for other d-c testing and calibration work. Storage batteries are commonly provided for this purpose and equipment for servicing and charging them must also be installed. The economic life of storage batteries can be greatly extended through adequate maintenance. Electronic-regulated rectifiers may also be used for d-c supply.

STANDARDIZING EQUIPMENT

Some regulatory bodies require that each operating utility maintain precision standards or rely on a laboratory of recognized standing for the purpose. In a large company with several operating divisions it may only be necessary to have such equipment in one location, although in some instances better efficiency may result in having similar equipment in each of the larger divisions.

A full description of such precision standards, together with recommendations for their maintenance and testing, is given in Section 12—The Meter Laboratory.

MAINTENANCE EQUIPMENT

Portable Standard Watthour Meter Test Tables

The checking or calibration of portable standard watthour meters, whether against a laboratory standard watthour meter or against a laboratory standard wattmeter, requires a means of loading, an accurate determination of load values and means for holding such load values constant. Such equipment is usually of a more precise type than that used in watthour meter testing and has more accurate means of control. Fig. 11-3 shows a test table for this purpose. This particular table is equipped with a phase shifter and a circuit for standard clock or timer control of the potential to the meter under test.

Watthour Meter Test Tables

Figs. 11-4 to 11-13 show several types of watthour meter test tables. These test tables generally provide a readily controlled current-loading circuit, voltage circuits of various values, means for conveniently locating and connecting a reference standard and means for conveniently mounting and connecting the meters under test. Automatic and other features may be added to make them more adaptable to special situations and constitute the major differences between types. A source of compressed air that is both clean and dry is essential for properly cleaning meters.

Fig. 11-4 illustrates a watthour meter test table of the simplest type

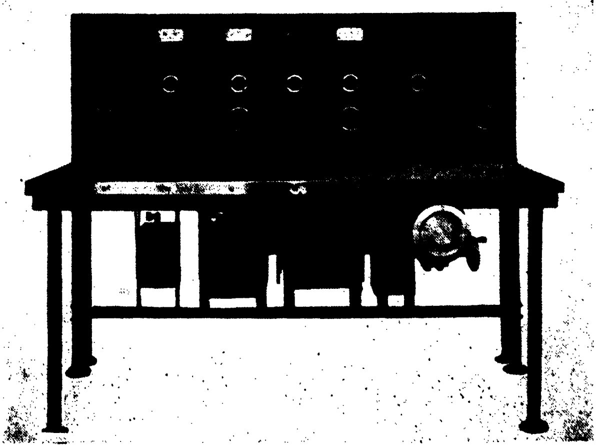


Fig. 11-3. Typical Portable Standard Watthour Meter Test Table

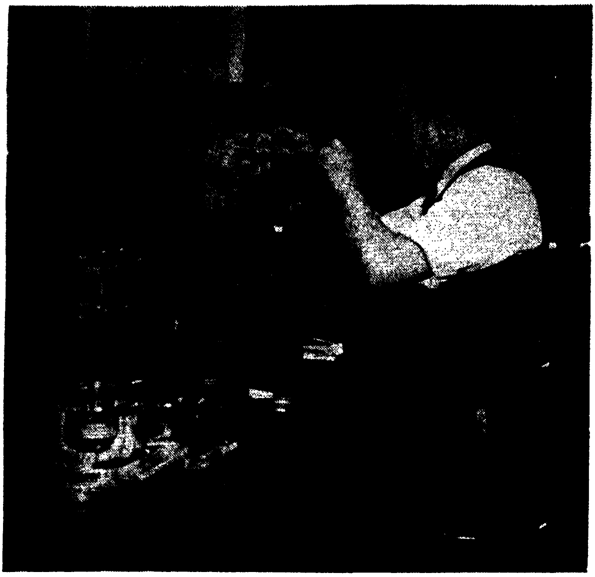


Fig. 11-4. Typical Single-Phase Test Table

intended primarily for single-phase meters.

Fig. 11-5 illustrates a test table designed for testing alternating-current watthour meters, both single-phase and polyphase. This table utilizes the "Uniload" system in which multi-range current and potential transformers are connected in the current and potential circuits respectively and whose secondaries supply the standard meter, thus permitting the standard to operate on the same range irrespective of the rating of the meters under test. This table also has a photo-electric timer which makes it unnecessary for the meter tester to count the disk revolutions or to start and stop the portable standard watthour meter. Also a high voltage insulation test may be applied to the meter winding while it is mounted for calibration, and both coils of a three-wire single-phase meter may be tested simultaneously without opening the potential links. See Fig. 11-6 for the essential wiring diagrams.

Fig. 11-7 illustrates a gang type watthour meter test table for testing simultaneously six single-phase watthour meters. It is equipped with the Knopp "Uniload" system of loading, automatic revolution counting facilities and push buttons for inching all meters and standards either forward or backward to the exact desired position.

Fig. 11-8 illustrates a dead front watthour meter test table equipped with combined stroboscopic and photoelectric units designed for testing alternating-current watthour meters, both single phase and polyphase of both the detachable and bottom-connected types. A high voltage insulation test may be applied to the meter windings while the meter is in the regular test position.

Fig. 11-9 illustrates a watthour meter test unit which may be arranged to test bottom terminal or detachable type watthour meters.

Fig. 11-10 illustrates a compact watthour meter testing unit which is completely self-contained. In general, the test board can be used for testing any watthour meter having one or two current coils and by means of suitable adapters either bottom-connected or detachable meters can be tested.

Fig. 11-11 illustrates a three-position watthour meter test table intended primarily for two- and three-element polyphase meters. Note the dial type selector switches for selecting connections and current and potential values and also the plug and cable connections for meters under test. A compressed-air gun and an extension light are provided at each position and complete individual panel lighting is used. Fig. 11-12 illustrates electronic automatic watthour meter test equipment developed by the Philadelphia Electric Co.

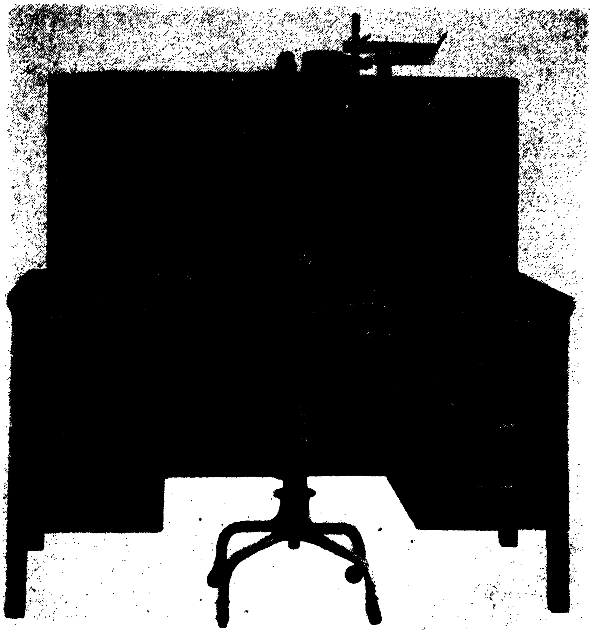


Fig. 11-5. Uniload Type Meter Testing Table (Electrical Facilities, Inc.)

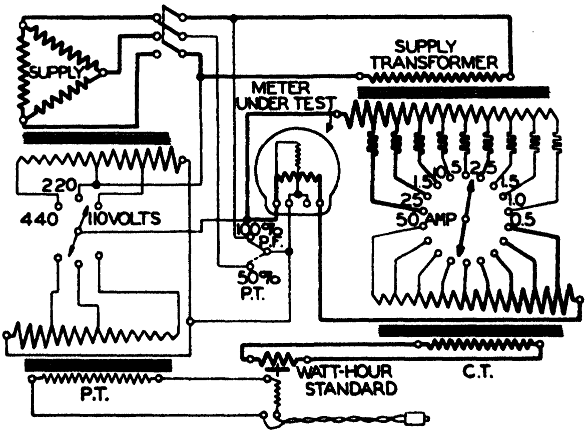


Fig. 11-6. Circuit Diagram of a Watthour Meter Testing Equipment Shown in Fig. 11-5

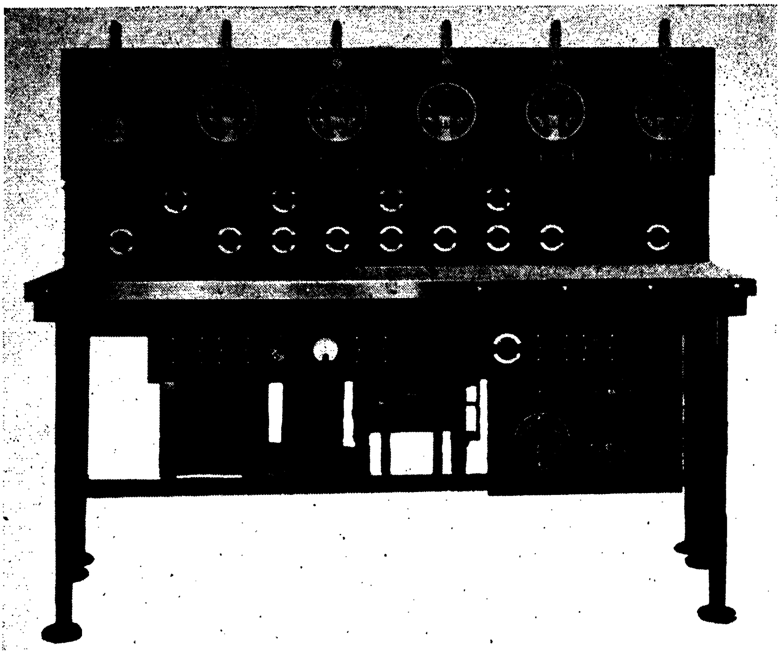


Fig. 11-7. Automatic Gang Type Test Table

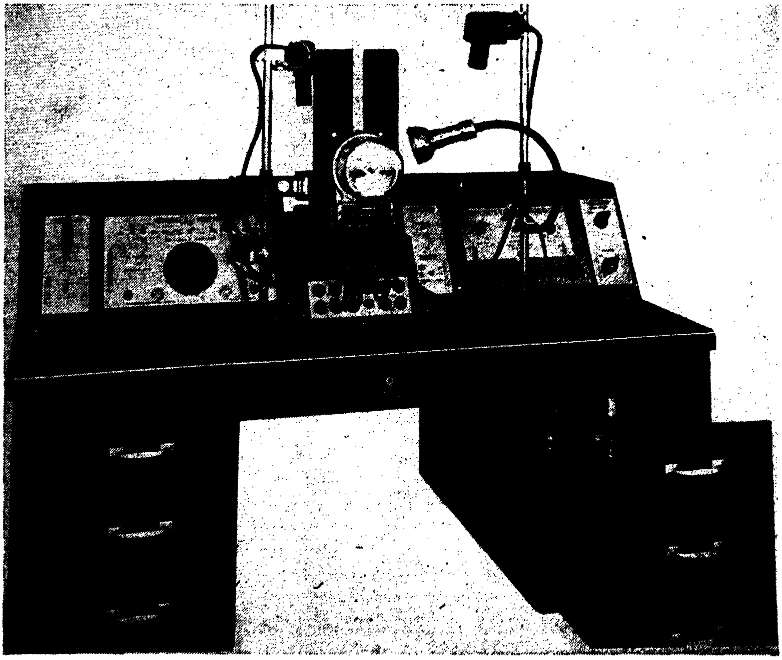


Fig. 11-8. Dead Front Meter Test Table (The States Co.)

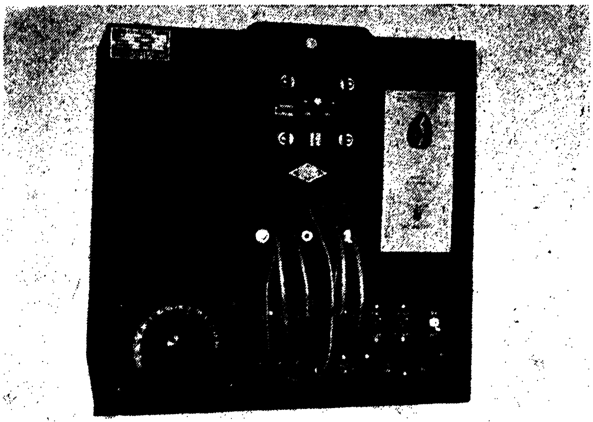


Fig. 11-9. Semi-Portable Watthour Meter Testing Unit (The States Co.)

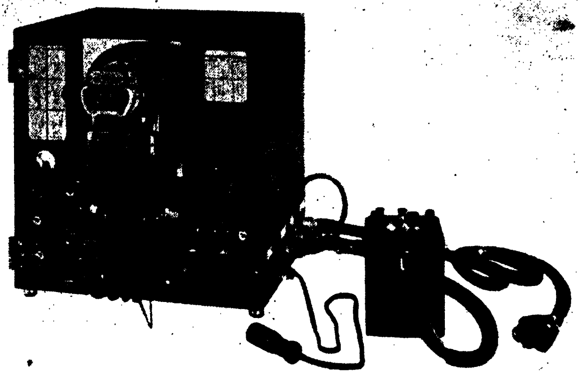


Fig. 11-10. Semi-Portable Watthour Meter Testing Unit (Eastern Specialty Co.)

Light impulses through the anti-creep holes in the disk of the meter under test control the operation by means of a photo-electric cell, an electronic amplifying system, selector relays and auxiliary relays. This includes stopping and starting the standards, and the changing of the test loads, including power factor.

Three watthour meter standards are mounted so that a projection system produces an image of their disks on ground-glass screens. The disks are provided with photographic film transparency inserts which, when projected on the ground-glass screens shown in the figure, permit the operator to read directly the percentage error of the meter under test. The readings remain until reset by the operator.

One of four push buttons allows the operator to start a sequence run, which includes a light load, full load, and inductive load test, after which the meter under test is automatically de-energized and necessary adjustments may be made.

The three other push buttons select any individual load for test. The operation of any one of the push buttons causes the relays to reset the standards to zero after which the proper circuit is automatically selected and load applied to the meter under test.

Provision is made for testing two-

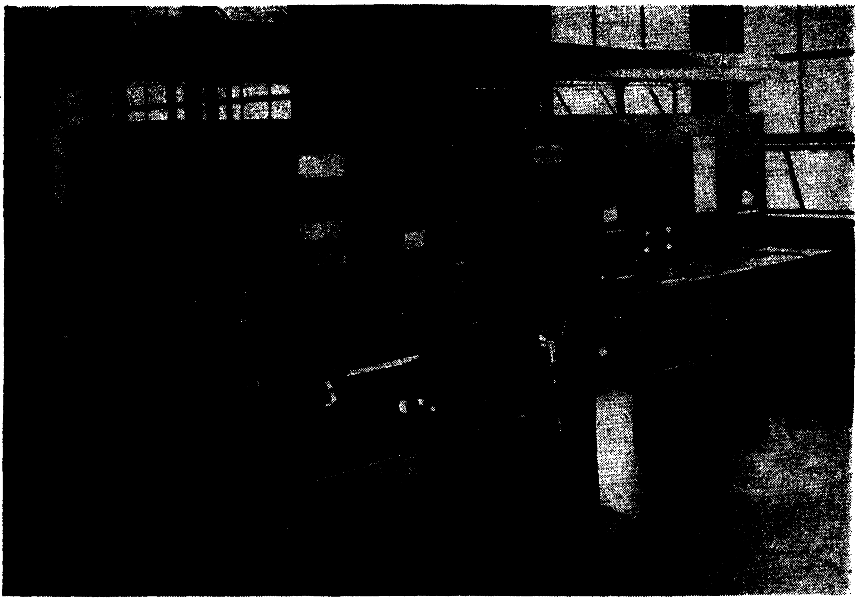


Fig. 11-11. Three Position, Dead-Front Polyphase Meter Test Board (Eastern Specialty Co.)

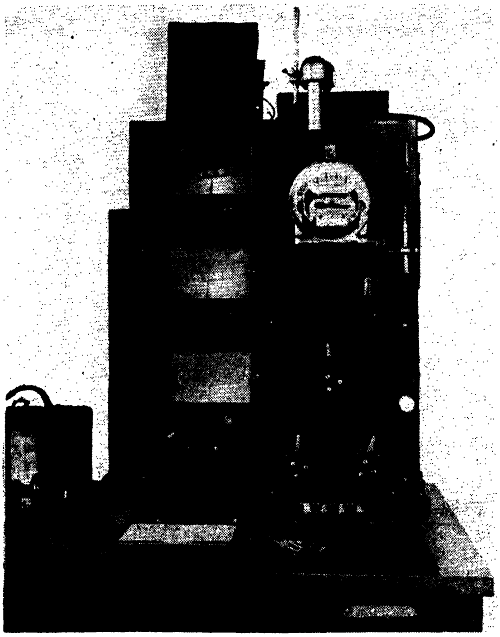


Fig. 11-12. Electronic Automatic Watthour Meter Test Equipment (Philadelphia Electric Co.)

wire and three-wire meters in ratings from 5 to 75 amperes.

Fig. 11-13 illustrates photo-electric watthour meter test equipment produced by The Eastern Specialty Company. The equipment consists of two complete test boards, two portable standard watthour meters, two photo-electric units (each of which includes a lamp, photo cell and supporting stand) and one General Electric Company photo-electric revolution counter. One operator can test two meters at a time using this arrangement. While the operator is making adjustments on one meter. The photo-electric equipment counts the revolutions of the second meter. The photo-electric equipment may also be used with only one watthour meter test board if desired. The photo-electric timer makes it unnecessary for the meter tester to count the disk revolutions or to start and stop the portable standard watthour meter.

Demand Meter Test Tables

Demand meters are usually operated in the shop for reasonable test periods before installation in the field so that operating difficulties after installation may be minimized.

Fig. 11-14 shows a demand meter test table for integrated demand meters which is provided with the usual current loading circuit of a test panel, a variable potential supply both single and three phase, a synchronous-motor-driven, variable-ratio, contact-making mechanism and positions for five or more meters, together with brackets for switchboard types. Fig. 11-15 shows another type of test table for contact-operated integrated demand meters.

Lagged demand meters of the thermal type, because of the testing time required, are usually tested in gangs. Fig. 11-16 shows a table for this purpose.

Time Switch Test Tables

Time switches, like demand meters, are usually run in the shop for a test period before installation and their operations noted. Fig. 11-17 shows a table for this purpose. The operation of a switch in each position is recorded on a graphic time recorder.

Meter Repair Tables

Repair tables should be conveniently arranged with respect to the work to be performed. Fig. 11-18 shows a typical meter repair table. It is recommended that tables be constructed of steel framework and that all working surfaces be covered with wear-resisting material. Provision should be made for storage of small parts, plug outlet receptacles, vise and insulation breakdown equipment. A stainless steel top may serve as a ground connection for breakdown testing. Industrial cleaning machines have been found very useful for the cleaning of demand registers and small meter parts in connection with repair operations.

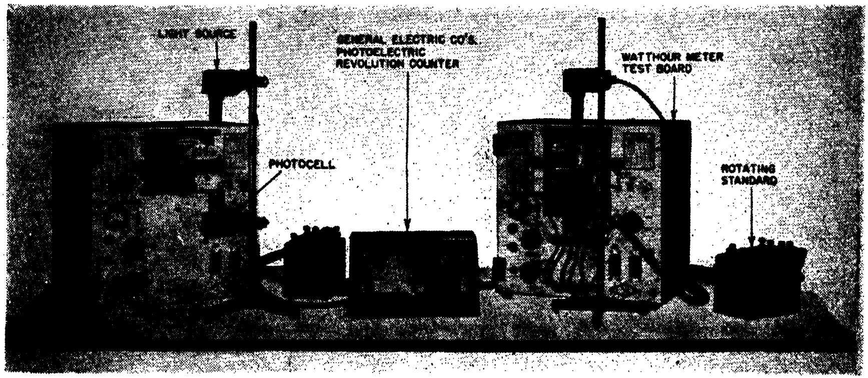

LIGHT SOURCE
GENERAL ELECTRIC CO'S. PHOTOELECTRIC REVOLUTION COUNTER
WATTHOUR METER TEST BOARD
PHOTOCELL
ROTATING STANDARD

Fig. 11-13. Photo-electric Watthour Meter Test Equipment (Eastern Specialty Co.)

Fig. 11-14. Typical Demand Meter Test Table

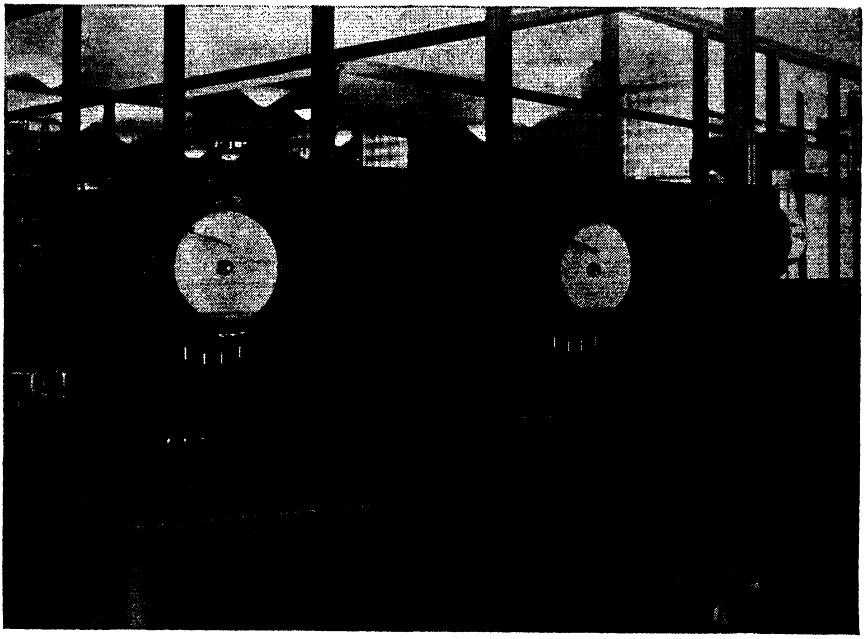


Fig. 11-15. Test Table for Contact-Operated Demand Meters

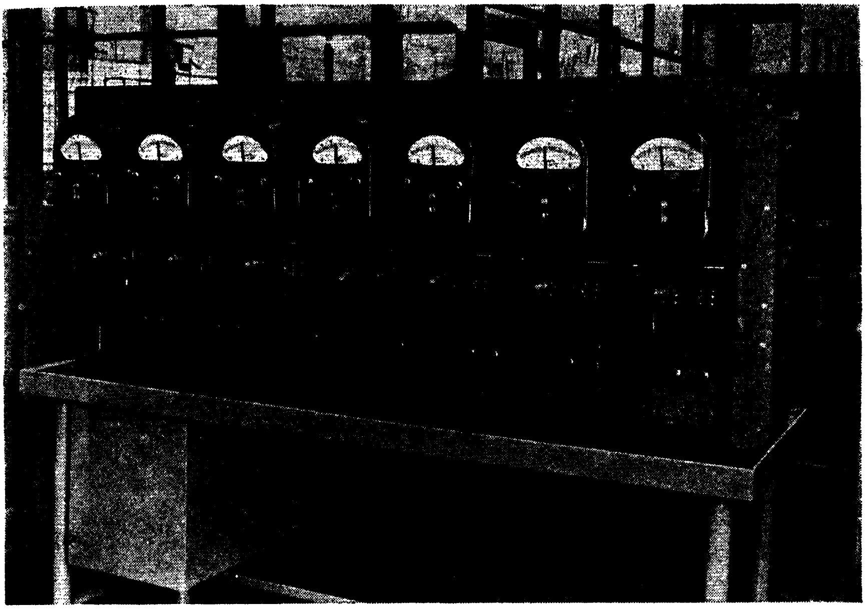


Fig. 11-16. Test Table for Thermal Demand Meters. This Table Provides for Mounting Meters on Both Sides. Fourteen Total

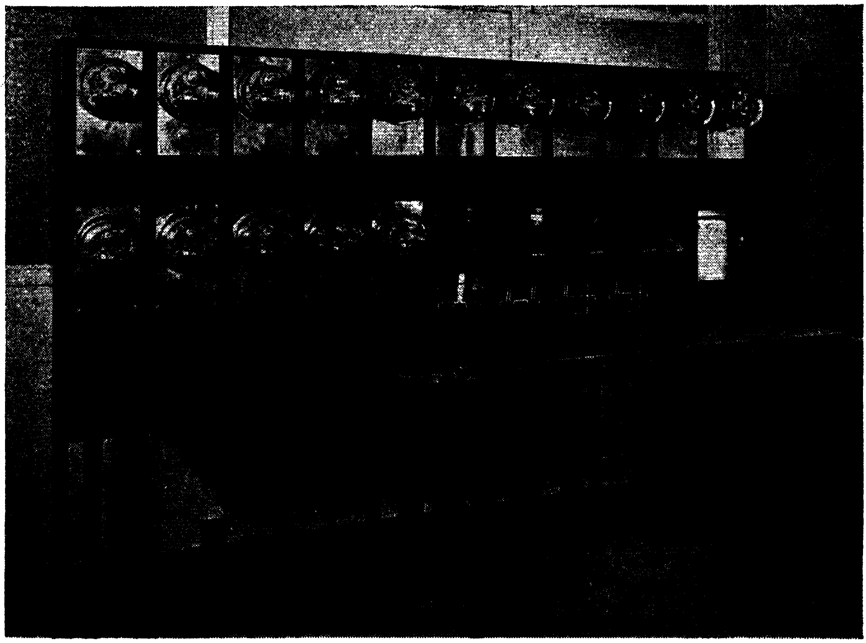


Fig. 11-17. Time Switch Test Table

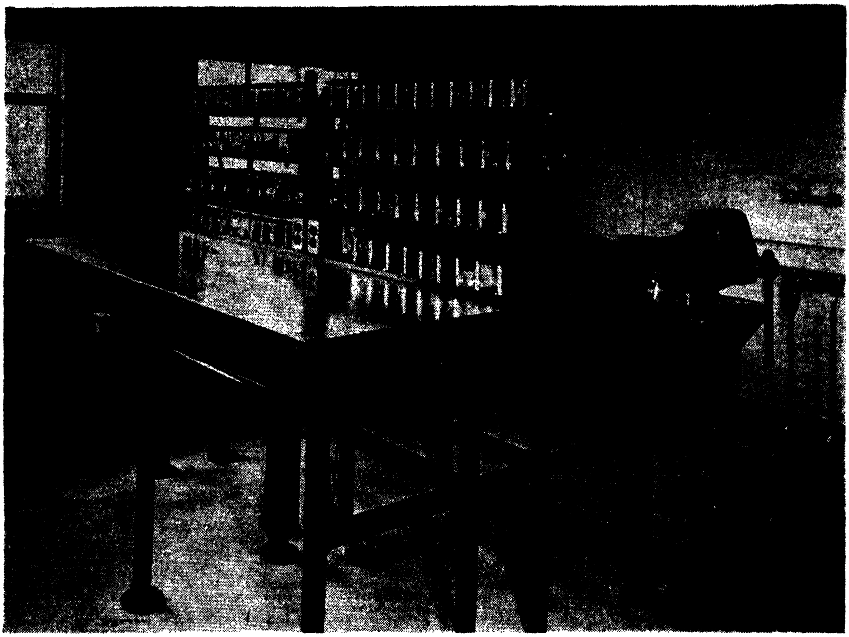


Fig. 11-18. Typical Meter Repair Table

Fig. 11-19. Portable Meter Rack

Meter Shop Trucks

Various types of small hand trucks, platform trucks and portable meter racks are used in the meter shop. One type of portable meter rack is shown in Fig. 11-19. This rack is moved by the use of a lift truck as shown in Fig. 11-20.

Shop Tools

Machine tools for the maintenance and repair of meters and meter devices may include a lathe, drill press, numbering machine and grinding and buffing equipment.

Painting Equipment

Paint spraying equipment for refinishing meters should include a spray gun, a source of regulated compressed air and a spray booth equipped with an exhaust fan and vent pipe to carry away fumes.

Instrument Transformer Testing Equipment

Shop equipment for testing instrument transformers requires, in addition to the measuring instruments and devices, a means of supplying and controlling the necessary primary current values for current transformers and primary potential values for potential transformers. The comparative method of testing is generally used. This requires a *standard* transformer with which the transformer under test is compared, and both must be connected in the loading and measuring circuits. Fig. 11-21 illustrates typical instrument transformer test equipment; including a table for test sets and instruments, a control panel, current loading transformers, and potential supply. The standard potential transformer and the transformer under test are in the background and the clamps for the standard current transformer and the transformer under test are at the right. It is extremely important that the equipment be designed in such a way as to protect the operator from exposure to hazardous potentials. Except for connecting the transformers under test, all connections are selected

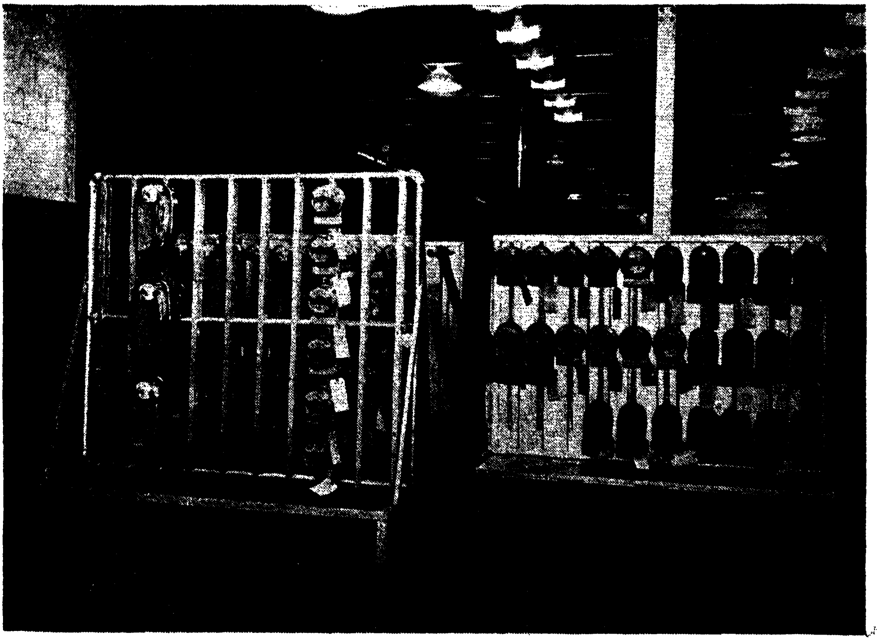


Fig. 11-20. Portable Meter Rack Showing Use of Lift Truck

by means of switches. Component equipment is so arranged that it may be readily disconnected and taken into the field.

Meter Jewel Bearing Inspection Equipment

New and used meter jewel bearings are usually inspected in the shop. Old jewels are first thoroughly cleaned. After cleaning, the jewels, pivots and balls are examined with a microscope and those considered unfit for further service are discarded. It is essential to provide adequate light in the jewel cups, free from shadows and reflections, to avoid false observations. Fig. 11-22 illustrates a typical inspection and cleaning table.

Rubber Goods Testing Equipment

The meter department may be required to examine and test periodically all rubber protective equipment used by employees. New equipment should always be inspected and tested before being placed in service.

The equipment required consists of a high voltage testing transformer of 2-kva minimum capacity with a regulator to provide smooth voltage adjustment from zero to maximum, instruments to determine voltage and leakage currents, tanks, water supply, drains, washing equipment and drying racks. Fig. 11-23 shows typical testing equipment.

INSTRUMENTS AND MEASURING EQUIPMENT FOR METER SHOP AND FIELD

Register Checking Devices

Before meters are placed in service, it is desirable that all registers be checked for ratio and mechanical adjustment. This check may be made by a time run on the meter or with a register checking device. There are a number of types of devices for checking ratios, but all essentially consist of a shaft to which is geared a standard register or a revolution counter, and which is provided with the neces-

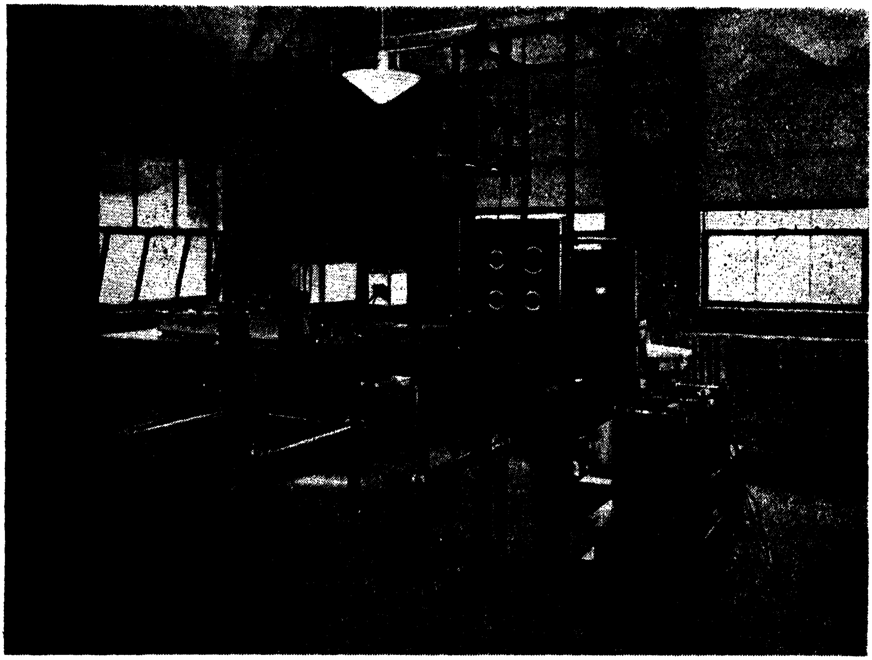


Fig. 11-21. Typical Instrument Transformer Test Equipment

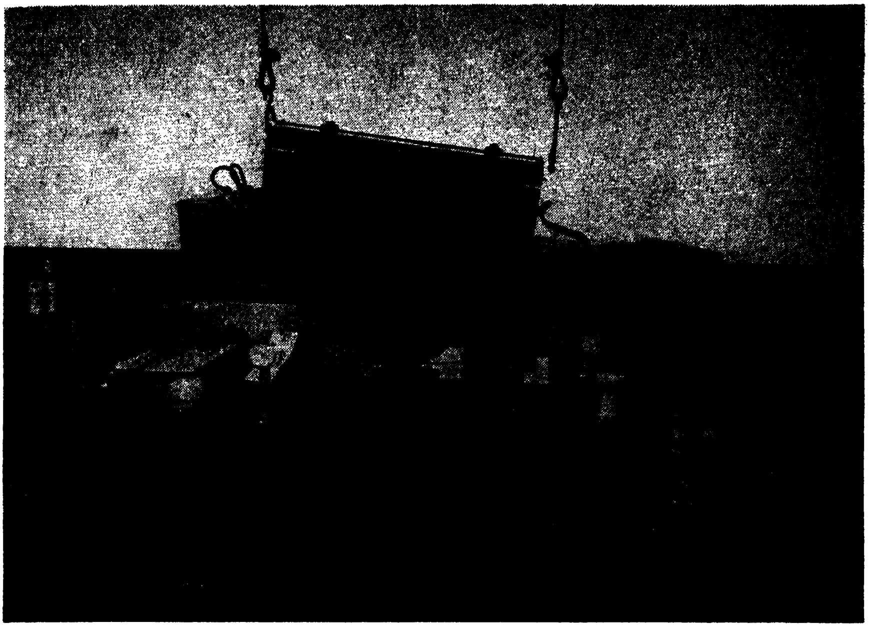


Fig. 11-22. Typical Meter Bearing Cleaning and Inspection Table

Fig. 11-23. Typical Rubber Goods Testing Equipment

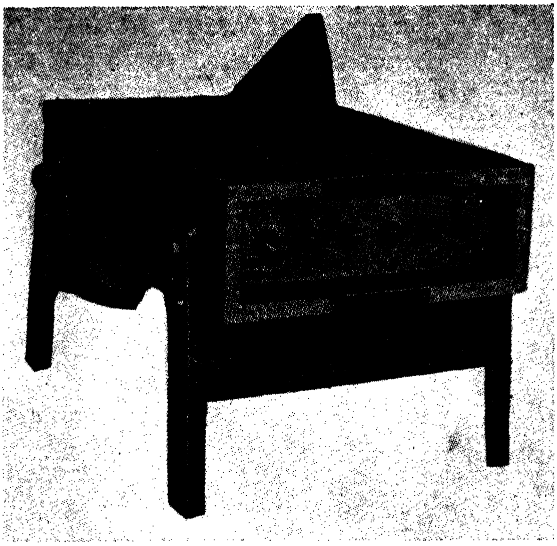


Fig. 11-24. Typical Resistance Load (Eastern Specialty Co.)

sary gears and mounting facilities for driving the various types of registers whose ratios are to be verified.

Portable Standard Watthour Meters

The portable standard watthour meter is a watthour meter similar to those used in commercial metering, but provided with certain special features. These features usually include several current and voltage ranges with means for selecting each one, a register which records the revolutions of the disk to the nearest hundredth of a revolution and which is equipped with a zero reset device, a disk brake to prevent creeping on current alone, and a fuse to protect the low capacity current coil. All coils are rigidly supported and carefully balanced to insure sustained accuracy. The entire mechanism is mounted in a rugged case with protecting cover so as to withstand the necessary handling.

It is essential that a portable standard watthour meter be given the closest attention. A new instrument should be subjected to a series of acceptance tests to determine whether it conforms to standard requirements. An instrument that is being used to test meters should have its calibration verified at frequent intervals. If any change in accuracy, other than allowable variations, is noted, the standard should be given a complete check before it is again used.

Portable standard watthour meters may be calibrated by comparison with a standard wattmeter and an accurate timing device such as a standard clock or by comparison with a reference portable standard watthour meter.

The leads used with a portable standard watthour meter and the potential test switch should be checked periodically. An ohmmeter or bridge may be used for the purpose of checking resistance.

Portable Type Loading Devices

The loading devices generally used are of two types, the resistance type for supplying the necessary current values at full line voltages and the transformer or phantom load type for supplying the current values at reduced voltages. The resistance type has the disadvantage of being limited in maximum current value because of the necessity of dissipating heat at a very high rate. The phantom load greatly reduces the rate at which heat must be dissipated. Fig. 11-24 illustrates a resistance load, and Fig. 11-25 illustrates a phantom load.

Ohmmeters

These are self-contained instruments with a potential source for measuring directly and reading on a scale, values of resistance within reasonable accuracy limits. Fig. 11-26 shows a type for comparatively low values of resistance.

Ohmmeters are also made for special work. One of these for measuring insulation resistance is shown in Fig. 11-27, and one for measuring the resistance to earth of grounding electrodes is shown in Fig. 11-28. Both of these instruments are provided with hand-driven self-contained generators to supply potential.

Clip-On Type Ammeters

There are available several self-contained ammeters which clip on a current-carrying conductor in a similar manner to split-core type current transformers and which measure the value of current in the conductor with reasonable accuracy. Figs. 11-29 and 11-30 show two examples of such instruments.

Graphic or Curve Drawing Instruments

These instruments are available for recording various measured quantities with respect to time. The most common types have a deflection measuring element which drives a recording pen or stylus across a moving paper chart a distance proportional to the quantity being measured. The moving chart is driven by a clock or motor-driven mechanism at a speed proportional to time at a desired rate. Thus a curve or graph results which shows the variation of the quantity measured with respect to elapsed time. Such instruments are available to measure the various quantities for which deflection type instruments are available. Figs. 11-31 and 11-32 show two such instruments of the portable type. Graphic meters are also available for switchboard or surface mounting.

Instruments of the type described above require a considerable amount of energy to drive the recording element and where the quantities to be measured are very small, they are not suitable for the purpose. For measurements requiring great sensitivity, photo-electric, potentiometer, and other types of recorders have been made available.

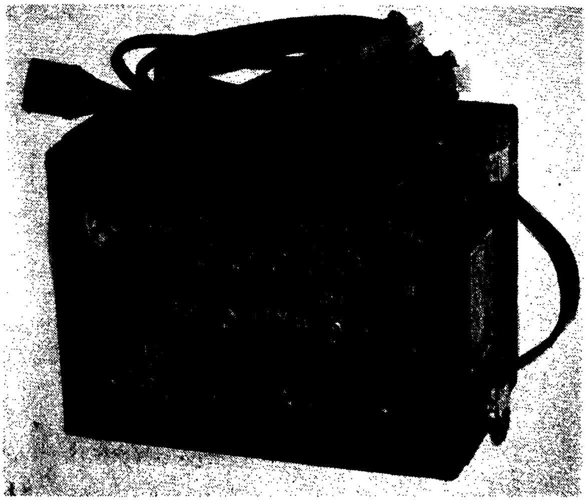


Fig. 11-25. Typical Loading Transformer—Phantom Load (The States Co.)

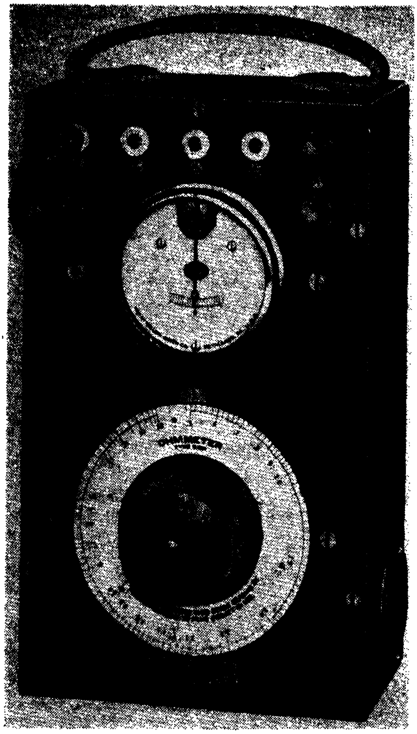


Fig. 11-26. Null Balance Type Ohmmeter (Roller-Smith Co.)

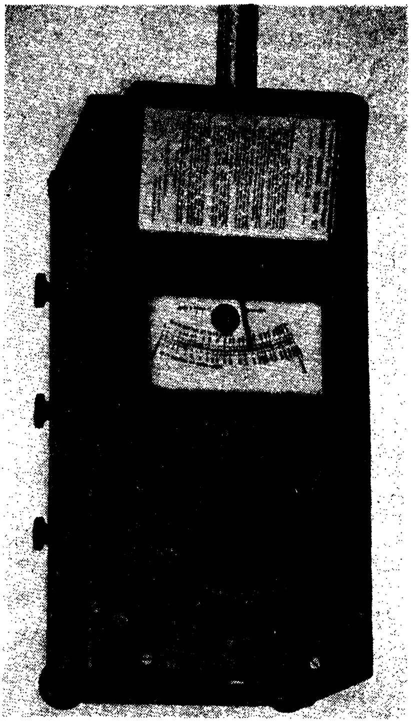


Fig. 11-28. Megger Ground Resistance Tester (J. G. Biddle Co.)

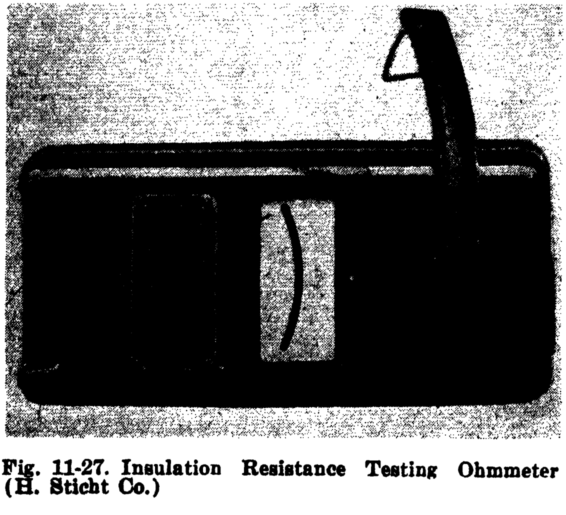


Fig. 11-27. Insulation Resistance Testing Ohmmeter (H. Sticht Co.)

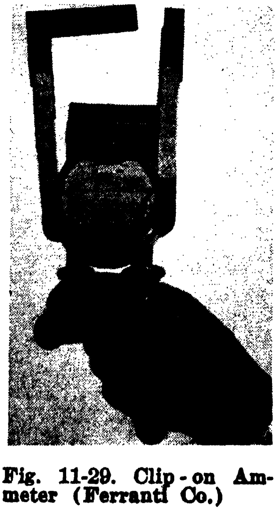


Fig. 11-29. Clip-on Ammeter (Ferranti Co.)

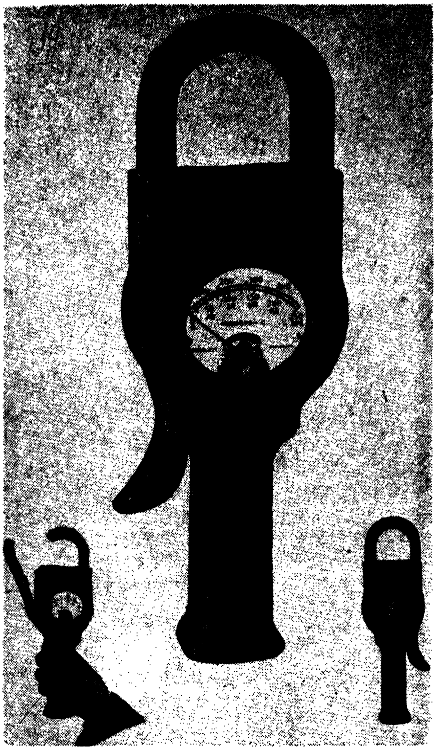


Fig. 11-30. Clip-on Ammeter (Weston Electrical Instrument Corp.)

Current Transformer Testing Equipment

Fig. 11-33 shows the Silsbee current transformer test set which is used for determining the ratio and phase angle of a transformer under test by comparing it with a standard transformer of known characteristics. The equipment balances the drops in variable resistances and a mutual inductance produced by the currents from the transformer under test and the standard transformer against each other. The relative value of the resistance together with the value of inductance required is a measure of the difference in ratio and phase angle. Fig. 11-34 shows the phase shifter used with this test set.

Potential Transformer Testing Equipment

Fig. 11-35 shows a potential transformer test set for testing potential transformers in a similar manner to that in which the Silsbee test set applies to current transformers. It uses a similar null method and the same type of galvanometer and phase shifter and compares the characteristics of a standard transformer with those of the one under test.

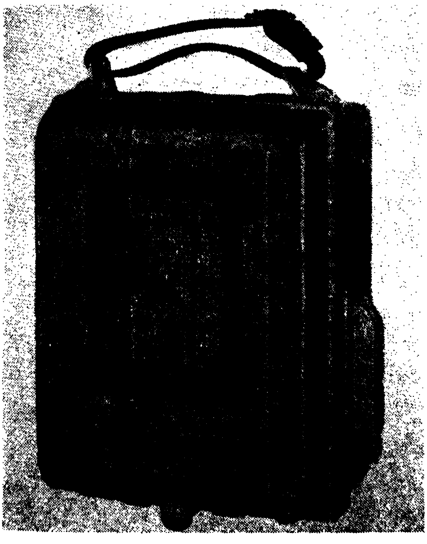


Fig. 11-31. Graphic Voltmeter (General Electric Co.)

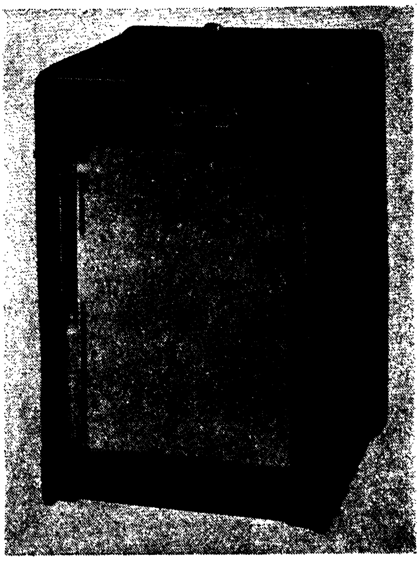


Fig. 11-32. Graphic Wattmeter (Esterline Angus Co.)

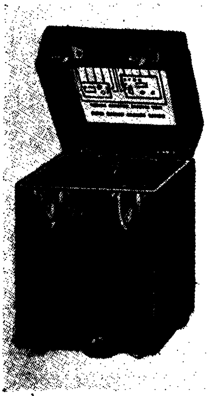
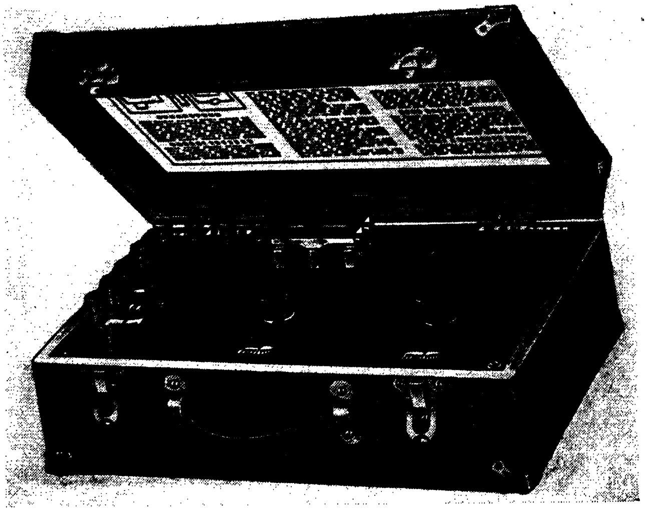


Fig. 11-33. (*top*) Silsbee Current Transformer Test Set (Leeds & Northrup Co.)

Fig. 11-34. (*left*) Three-phase Phase Shifter used with Leeds and Northrup Current and Potential Transformer Test Sets

Fig. 11-35. (*below*) Potential Transformer Test Set—Comparative Method (Leeds & Northrup Co.)



PRECAUTIONS IN USING PORTABLE INSTRUMENTS AND METERS

Electrical standards, in general, are of delicate construction, and should, therefore, be handled with extreme care.

In setting up apparatus for test, the standards should be located with due attention to sufficient light, convenience and comfort in reading, steadiness of support, leveling, avoidance of extremes of temperature, the influence of external magnetic fields, and vibration.

Care of Instruments

Instruments should be handled gently and should receive no shock or blow from contact with table, bench, or other instruments, in order to avoid damaging the fine points of the pivots or the polished surface of the jewels. In placing an instrument into its carrying case, the case should be laid flat and the instrument slid slowly into it. The base or cover should not be removed from any instrument outside of the laboratory, as foreign particles are almost certain to get into the instrument.

Precaution should be taken to insure that the current and voltage are within the range of the instrument about to be used. A voltmeter used in measuring the voltage across a highly inductive circuit may be damaged by the inductive *kick* due to the collapsing of the magnetic lines of force; such a condition would arise in the case of a direct-current voltmeter used in connection with an ammeter for the measurement of the resistance of a transformer, if the circuit is broken before the voltmeter is disconnected.

When a wattmeter potential circuit or a voltmeter is connected across part of a circuit in which the line voltage is higher than the maximum range of the instrument, it is important that the part of the circuit between the instrument terminals should not be broken while the instrument is connected. To do so would, in most cases, place the total line voltage across the meter. Disconnecting a series instrument while the potential instruments are connected to the line side of it, is a common cause of such accidents.

It is best to keep portable voltmeters disconnected at all times when readings are not being taken. Series instruments can be protected to some extent by having switches arranged to short-circuit them, the switch being opened only when a reading is to be taken. Fuses or circuit breakers can be used to prevent the winding from being actually burned out, but they cannot prevent the mechanical shock to the moving element when subjected to such overload. With series instruments having a considerable resistance, a short-circuiting switch may not be applicable, especially if the voltage of the circuit is low. If the current were adjusted with the instrument in the circuit, the short-circuiting of the instrument might cause an undesirable rise of current.

When using wattmeters on circuits of 500 volts and upward, the moving element should be protected by connecting the correct potential post (depending on the type of instrument employed) to one of the current posts. Either current post may be used; but if the one connected directly to the load is chosen, the indication of the wattmeter will include the watts lost in its own potential circuit, and a correction may be desirable.

INFLUENCE OF TEMPERATURE

Direct-Current Instruments

Temperature effects are inherent in almost all electrical instruments. The temperature error of a direct-current voltmeter is principally due to changes in the permanent magnet flux and in the strength of the springs. The change in the resistance of the electrical circuit of a high grade voltmeter is usually negligible since this circuit consists of a few ohms of copper wire in series with thousands of ohms of resistance wire, having an extremely low temperature coefficient.

Direct-current ammeters usually have higher temperature coefficients than voltmeters because their electric circuit is composed chiefly of copper.

In ammeters operating on the millivoltmeter principle, the temperature coefficient may be greatly reduced by using shunts with a relatively large drop, e.g., 200 millivolts, thus allowing the use of manganin wire in series with the copper coil. In connection with the question of temperature errors of millivoltmeters, those due to the heating of the shunts are very important. On account of temperature differences, thermoelectric effects may produce considerable error. The thermoelectric effect may be observed by passing current through the shunt until it has reached operating temperature; if upon opening the main circuit, the millivoltmeter shows a small deflection, the presence of a thermoelectric effect is indicated. This effect may be produced by any condition which causes unequal heating of the ends of the shunt, such as a poor contact at one end or a difference in the size of the conductors connected to the shunt.

The temperature effects on direct-current portable standard watthour meters are due to the changes in resistance of the disk and the armature or potential circuits. In the older types of standards, the disk was of copper or aluminum having high temperature coefficients of resistance. The modern type of standard is designed with a disk made of an alloy having a low temperature coefficient of resistance. Also the armature has no appreciable change in its resistance due to temperature and has a coefficient similar to that of the disk. This design eliminates the need for external compensating devices and of special heating of the armature circuit before using the meters.

Alternating-Current Instruments

In the movable-iron type ammeter, with spring control, increase of temperature not only lowers the permeability of the iron, but also reduces the strength of the spring in nearly the same amount; hence these ammeters are very nearly independent of ordinary temperature changes.

In the movable-iron voltmeter, the temperature coefficient depends mainly upon the ratio of the resistance of the copper coil to the total resistance of the instrument. This ratio is a question of design depending upon the range of the instrument and the amount of power expended. For the usual commercial voltages, the temperature coefficient of well-made voltmeters of this type is quite small, and for practical work need not be taken into account.

In the electrodynamometer type instruments, the only element of importance in respect to temperature coefficient is the controlling springs. Such instruments will read slightly low at temperatures below those at which they are correct.

The temperature effect on modern alternating-current portable standard watthour meters is negligible throughout the normal working temperature range.

INFLUENCE OF STRAY FIELDS

Stray fields may cause appreciable errors in instruments. Such stray fields may be produced by other instruments, conductors carrying heavy currents, generators or motors. Even non-magnetized masses of iron may affect the flux in an instrument. If circumstances compel the making of tests in places subject to strong stray fields, the instrument may be read, then turned 180 degrees, read again, and an average taken.

Some instruments of the electrodynamometer type are made astatic, in order to avoid the errors due to stray fields, by having two movable coils so connected that a stray field, if uniform, produces equal and opposing torques on both.

Direct-current portable standard watthour meters are affected by stray fields in a manner similar to direct-current instruments. They should always be set up with the plane of their current coils parallel to the lines of force of the stray fields.

Alternating-current portable standard watthour meters are very little affected by stray fields.

MECHANICAL EFFECTS

Mechanical faults causing errors may include pivot friction, defective springs, incorrectly marked scales, and unbalance of the moving coil.

Pivot friction is usually caused by improper handling of an instrument and is usually due to cracked jewels or bent pivots.

Zero shift of the pointer may follow a prolonged deflection. This is usually temporary. Indiscriminate resetting to zero by means of the spring adjustment is not recommended. Zero shifts caused by a bent pointer should be corrected by straightening the pointer rather than by zero adjustment.

Lower grade instruments usually have fixed printed scales but a standard instrument should have a scale calibrated to fit it. The simple removal and replacement of the pole pieces of a direct-current instrument—in fact, even the tightening of the screws that hold the pole pieces—will affect the distribution of the magnetic flux so that a scale which fitted the instrument before the operation will show appreciable errors thereafter. Therefore, the accuracy of the scale marking should be checked following any mechanical change, adjustment, or accident to an instrument.

Another mechanical effect is the imperfect balancing of the moving system. This may be detected by holding the instrument in various positions with no current flowing through it. A portable direct-current voltmeter examined in this way will show a change of zero reading of not more than a few tenths of a scale division if in good balance; millivoltmeters, wattmeters, and alternating-current instruments, all of which usually have a smaller ratio of torque to weight than the direct-current voltmeter, may show as much as one division. If an instrument shows considerable variation of the zero reading when examined as above, it should be re-balanced.

Another effect is that due to electrostatic action between the moving part of the instrument and some fixed part. Rubbing the glass cover, or even moving an instrument reading glass over the pointer, will often cause it to move from its proper zero position, due to the action of an electric charge produced on the glass. The remedy for this consists in breathing on the glass, the moisture causing the charge to leak away. A similar effect has been noted when calibrating wattmeters by the method of separate sources of current and voltage. When the potential of the fixed coil is appreciably different from that of the moving coil, an electrostatic force is exerted between the two which may introduce errors into the readings. The remedy is to arrange the circuits so that the fixed coil and the moving coil may be joined together at one point. This requires care to avoid trouble due to contact between the circuits at some other point.

The matter of good electrical contact is an important one in connection with the use of electrical instruments. One case in particular is that of the direct-current millivoltmeter used with separate shunts as an ammeter. The millivoltmeter is connected to the shunt by two leads, and in most instruments now in use this involves four contacts in the instrument's circuit, two at the shunt and two at the instrument binding posts. As the resistance of the instrument is only a few ohms, a loose, corroded or dirty terminal or binding post surface may introduce errors which amount to several per cent.

ACCURACY OF OBSERVATIONS

The accuracy of observations or readings depends partly upon the construction of the instrument and partly on the skill of the observer. Where accurate readings must be taken, it is the general custom to use a knife-edge pointer, in connection with a mirror, to avoid parallax.

The accuracy of observation in reading any instrument varies with the deflection of the instrument, the larger the deflection the smaller the error. For example, an instrument has a scale of 100 equal divisions, which can be read to one-tenth of a division. The reading error at full scale is then 0.1 per cent and at scale division 10 it is one per cent (assuming a uniform scale). This emphasizes the necessity of selecting such instruments in a test that the readings are well up the scale.

SECTION 12

THE METER LABORATORY

SCOPE AND FUNCTIONS

The designation of laboratory is very often applied to the meter shop but for the purpose of this section it will be assumed to apply to a separate division of the meter department. The scope of a meter laboratory may include only the certification of portable standard watthour meters and portable instruments or may be extensive and include any or all of the following: acceptance tests of materials and apparatus, special investigations and research work. The fundamental responsibility of a laboratory is to obtain accurate measurements. Most of the larger utilities have such laboratories; but other organizations, due to consideration of size or local conditions, find it more practical to have some or all of these activities performed elsewhere, sometimes by outside agencies such as other utilities or by public or private laboratories of recognized standing qualified for such work. Unless a utility is very small, however, it will usually find it advantageous at least to maintain secondary standards for the testing of its portable working standards. Large utilities frequently maintain meter laboratories for this purpose in local operating units and have a complete standardizing laboratory at a headquarters location.

The basic functions of a meter laboratory are as follows:

1. Calibrating and certifying the accuracy of working standards.
2. Calibrating and certifying the accuracy of secondary standards. A meter laboratory must maintain the accuracy of its own secondary standards by comparing them with its primary standards, and may also certify to the accuracy of secondary standards of meter laboratories in distant divisions of its company, or in other organizations, by comparing them with its own secondary or primary standards. A utility that does not maintain primary standards of course cannot perform this function, but instead must have its secondary standards calibrated for it periodically by an approved laboratory, and in the interim should assure itself of their accuracy by intercomparing them regularly.
3. Intercomparing primary standards. The standard resistors, standard cells and associated equipment employed to calibrate its secondary standards are the laboratory's highest internal authority on the value of electrical measuring units. These primary standards are not employed directly to test working standards because the procedure involved in using them is necessarily slow and, where a large number of tests must be made, the time consumed would be prohibitive; hence the practical need for secondary standards.
4. Having primary standards certified regularly. Primary standards should be sent periodically for certification to the National Bureau of Standards. If this is deemed impractical, they should be certified by an approved laboratory that has its own primary standards regularly certified by the National Bureau of Standards.
5. Making acceptance tests and determining the characteristics of new types or designs of watthour meters, portable instruments, instrument transformers, and other electrical measuring devices to determine their compliance with requirements from the standpoints of accuracy, stability, ease

of maintenance, and general suitability.

6. Making special investigations relating to metering or measurement problems. The purpose may be to find and remove, if possible, the cause of some obscure source of error, or perhaps to compare the relative merits of two or more proposed schemes for accomplishing a desired result. This may involve setting up circuits and conditions in the laboratory similar to those in the field in a way that allows various influencing factors to be controlled and their effects determined, or permits trial operation of a scheme before installation in the field.
7. In addition to these basic functions, the meter laboratory may include in its scope of operations the repair of electrical instruments and related devices.

FUNDAMENTAL STANDARDS

The basic electrical units, the ohm, the ampere, and the volt, have been established by international agreement in conferences attended by scientists from many of the leading nations of the world. Countries such as the United States, England, France, Germany, and Japan maintain bureaus of standardization in which duplicates of these units, or the means for producing the units are kept under conditions which insure their permanency. As a further check upon the constancy of the units, intercomparison is made periodically.

In the United States, the source of ultimate authority in electrical measurements, and our representative in the international system of standardization, is the National Bureau of Standards of the Department of Commerce at Washington, D. C. Here basic units are preserved, together with secondary units and high grade instruments by means of which commercial measuring devices may be compared with these basic units.

Starting with the Bureau of Standards, a comprehensive system of standardization has been developed. Facilities are available whereby each utility may be assured of the accuracy of its measurements and may have its standards compared with the basic units at Washington.

The two fundamental standards of electrical measurement are the *absolute ohm* and the *absolute volt*. Standard cells and standard resistors, referred to as primary standards, are used as a means of maintaining these fundamental standards in a meter laboratory. From these standards, the values of other units of electrical measurements can be derived.

LIST OF ESSENTIAL LABORATORY EQUIPMENT

The equipment of a meter laboratory should include the following primary, secondary and working standards and their related apparatus:

1. *Primary Standards*
   a) At least three cadmium standard cells.
   b) Standard resistors of such values and current-carrying capacities as may be required to cover the normal range of the laboratory in its standardizing work. These resistance standards should be provided in duplicate.
2. *Apparatus and Facilities Used with Primary Standards*
   a) A calibrated potentiometer having a range of 1.5 volts, adjustable continuously or in steps of 0.00001 volt.
   b) Two calibrated volt boxes of suitable ranges.
   c) A high sensitivity galvanometer of the D'Arsonval type.
   d) Storage batteries, or the equivalent, to supply steady d-c test voltages and test currents.
   e) Rheostats for regulating test currents and test voltages to within 0.01% of their value.
   f) Suitable reversing switches for eliminating the effect of the external magnetic fields, thermoelectromotive forces, etc.
3. *Secondary Standards*
   a) A laboratory standard type d-c indicating voltmeter.

b) A laboratory standard type d-c indicating ammeter, or a laboratory standard type millivoltmeter and shunts. (A deflection type potentiometer, readable to 0.01% of the maximum setting of the main dial, with suitable volt box and shunts, may be substituted for items *a* and *b*).

c) A laboratory standard electrodynamometer type indicating voltmeter.

d) A laboratory standard electrodynamometer type indicating wattmeter. (Items *c* and *d* are frequently referred to as "transfer instruments." They are calibrated on direct current and then used as laboratory standards to calibrate alternating-current working standards.)

e) Two or more standard a-c watthour meters.

f) If direct-current distribution is employed, two or more standard d-c watthour meters, and instruments for the measurement of current, voltage, and time.

g) Current and potential transformers of suitable ranges, together with equipment for comparing their ratios and phase angles with those of instrument transformers submitted for test.

h) A Wheatstone bridge. While a meter laboratory may be able to perform its assigned duties without it, a Wheatstone bridge is almost essential equipment. It may also be convenient to have a Kelvin bridge if many low resistance measurements are required.

4. *Apparatus and Facilities Used with Secondary Standards*

   a) An accurately regulated pendulum clock provided with means for automatically making and breaking an electrical circuit.

   b) One or more phase shifters.

   c) A source for furnishing steady, approximately sinusoidal, a-c test voltages and test currents.

5. *Working Standards*

   Such portable standard watthour meters, portable indicating instruments (ammeters, voltmeters, wattmeters), stop watches and certified current and potential transformers as are required to test single-phase and polyphase service watthour meters, demand meters, switchboard instruments and meters, recording voltmeters, ammeters and wattmeters, and other electrical measuring instruments in use by the utility.

SELECTION OF INSTRUMENTS AND RELATED EQUIPMENT

The selection of instruments and related equipment best adapted to meet the requirements of a particular case is very important and should receive careful consideration. The most suitable types and ranges must be determined by the nature of the work for which they are to be used, and the degree of accuracy required.

The reliability of any instrument depends upon the type, design, materials, construction, and accuracy of calibration. While the basic operating principle of instruments of a particular class is the same, it is frequently true that there are features of construction and material which may be peculiar to the designs of certain manufacturers and absent from those of others. These features may or may not enhance the value of an instrument and, while the effect of some is very apparent, others, particularly those which may be detrimental, can be detected only by a critical examination and test. Therefore, it is best, prior to acceptance, to submit the instrument under consideration to a recognized testing laboratory for examination and certification of accuracy. This precaution affords the purchaser insurance against unsuitable instruments.

In general, instruments operating upon the null or balance principle are more accurate than deflection instruments. The potentiometer and instruments of the Kelvin balance type operate on these principles, while direct-reading voltmeters and ammeters are deflection instruments. Null instruments are required for work of the highest accuracy, but are expensive and involve slower methods. Deflection instruments are less expensive and permit faster operation.

All instruments should be as free as possible from the effects of temperature changes, stray fields, frequency variation, wave form, spring set, and vibration. Indicating instruments should be equipped with accurate, legible scales having plainly marked divisions, from which intermediate values can readily be determined.

LABORATORY LAYOUT

The physical arrangement of the laboratory depends so much on local conditions and its particular scope of operations that only general recommendations can be made.

It should be in a clean location, free

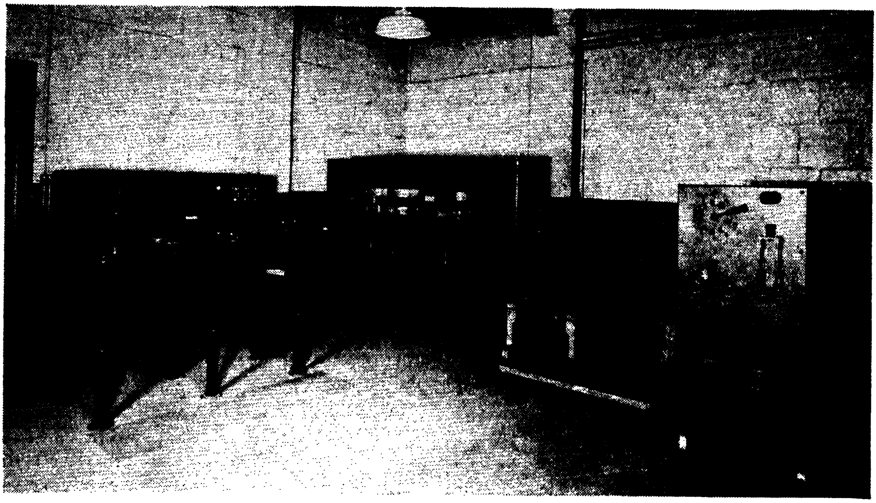


Fig. 12-1. Primary Type Current Transformer Testing Equipment Showing Loading Transformer and Clamp for Current Transformer

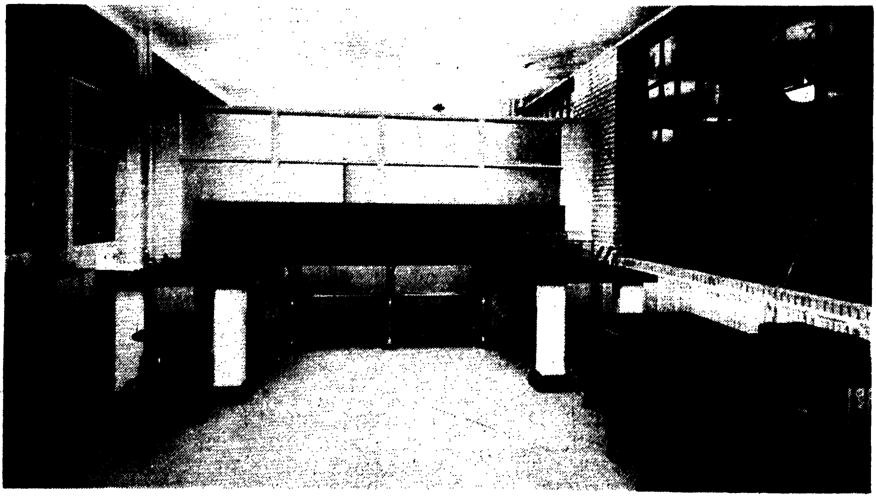


Fig. 12-2. Standardizing Room

from vibration, well lighted (preferably 30 or more foot-candles on working surfaces) and, if possible, in a room separate from other activities. Potentiometers and secondary standards should be installed so that they may be used in place and will not be subjected to jarring and other accidents that might affect their calibration. One plan that has wide acceptance is to install such instruments on one or more tables used for no other purpose and wired to other tables on which instruments to be tested are placed. By suitable switches the standards can be connected with the instruments under test, and yet remain physically isolated. Figs. 12-1, 12-2, 12-3 and 12-4 illustrate typical laboratory layouts.

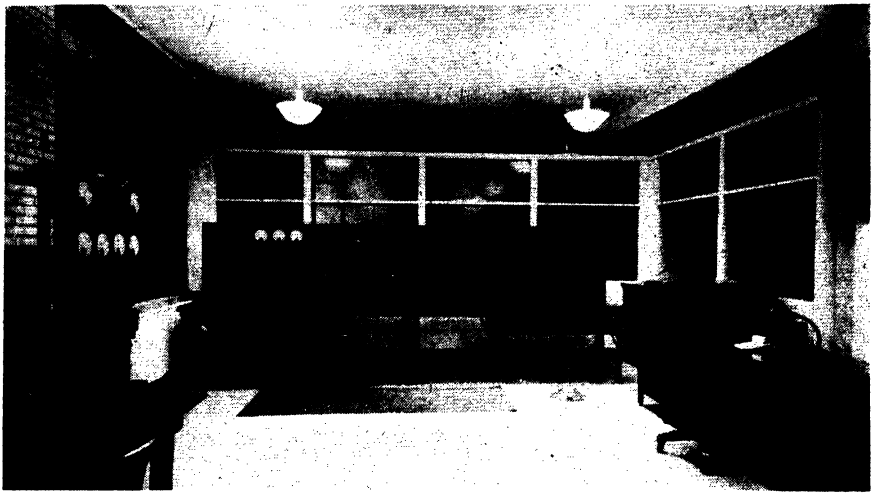


Fig. 12-3. Standardizing Room

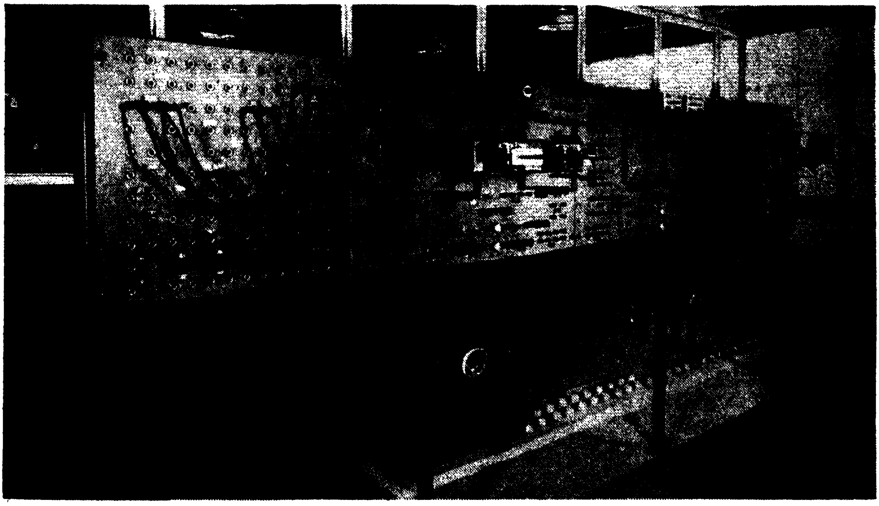


Fig. 12-4. General Relay and Instrument Test Table

STANDARD CELLS

The practical standard of voltage is the standard cell. This cell is made in two types, the saturated or so-called "normal cell," and the unsaturated cell. The former has a very definite voltage and a rather large temperature coefficient. The latter, while not having a voltage that can be exactly predetermined, has a voltage which remains very constant under proper usage and is free from temperature variations within the range generally experienced in the laboratory. This unsaturated cell is accordingly the one used in practically all standardizing work. Its construction is illustrated in Figs. 12-5 and 12-6. Several cells, at least three, should be owned by each laboratory.

The ambient temperature of the cells should be regulated to minimize fluctuations and at no time should the cells be subjected to temperatures lower than 4 C or higher than 40 C. Standard cells should be used in circuits where very little current flows, even during the process of balancing. Current in excess of 0.0001 ampere passing through a standard cell is likely to damage it. The average electromotive force is approximately 1.0186 volts and the resistance approximately 100 ohms.

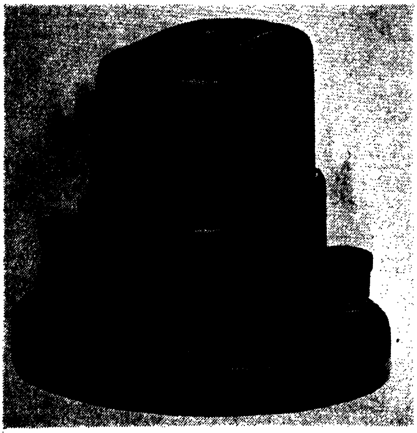


Fig. 12-5. Standard Cell (Weston Electrical Instrument Corp.)

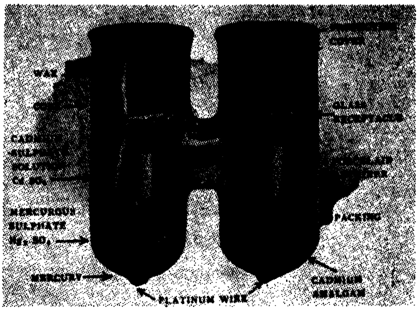


Fig. 12-6. Weston Standard Cell Construction

There will be slight changes in standard cells over long periods.

At least two cells should be set aside for use only as reference cells in making intercomparisons. The most accurate method of comparison is to oppose the emf's of the two cells and to measure the difference with a potentiometer whose battery current has been reduced to one-tenth of its normal value. This comparison can also be made by means of a potentiometer balanced to a reference cell, with the cell to be compared connected to the proper terminals.

STANDARD RESISTORS

The addition of current carrying resistors or precision shunts adapts the potentiometer and standard cells to precise measurements of current. The current to be measured is passed through a standard resistor, and the voltage drop is measured with a potentiometer. The value of the current can be determined by dividing the voltage drop by the resistance of the standard resistor. Fig. 12-7 illustrates an air-cooled resistor (shunt) for large currents. Fig. 12-8 shows a typical precision type resistor. The latter resistor is hermetically sealed to assure constancy, and, for operation at rated capacity within the limits of specified error, it must be used immersed in an oil bath at 25 C.

Two sets of standard resistors should be included in the laboratory

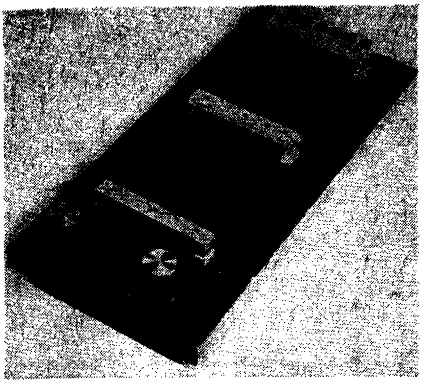


Fig. 12-7. Standard Laboratory Type Air-Cooled Resistor (Leeds & Northrup Co.)

equipment. The following are the ratings usually employed:

1.0 Ohm
0.1 "
0.01 "
0.001 "
0.0001 "

One of the 0.001 and one of the 0.0001 ohm resistors should be of large current-carrying capacity. The others may be of small capacity and serve only as reference standards.

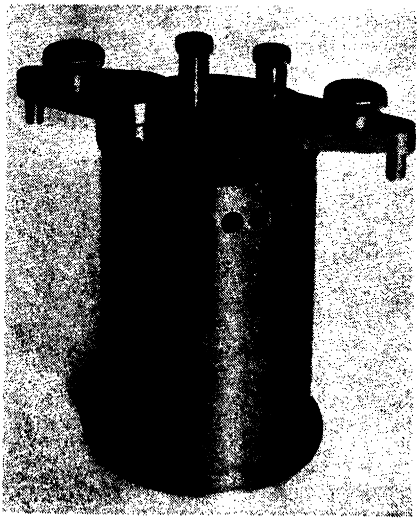


Fig. 12-8. Standard Resistor With Separate Potential Connections (Leeds & Northrup Co.)

Care should be taken that standard resistors are not overheated and, if oil-cooled, that only specially prepared oil is used. Both the current terminals and the potential terminals should be kept clean. Poor contact at the current terminals of large capacity resistors will produce excessive heating which may permanently change the resistance.

The changes that may be expected in resistors of this type when not overloaded are very small. Intercomparisons can be made by connecting two resistors in series with each other to a storage battery and rheostat. A Kelvin (Thomson) bridge is then connected to the potential terminals of the two resistors, and a balance is established by using a sensitive galvanometer. By using reasonable care, errors of measurement can be kept within 0.02%.

POTENTIOMETERS

Potentiometers are specially constructed and designed for measurements of unknown direct-current potential differences. Practically all emf and current measurements of precise character are now made with them.

Fig. 12-9 shows diagrammatically the fundamental principle of a potentiometer. A resistance, *ab*, is connected in series with a rheostat, *R*, and across a battery, *B*. A standard cell, E_s, and the unknown emf or potential difference, E_x, are connected to a suitable switching arrangement, so that each can be connected through a key and galvanometer to the resistance *ab* as indicated. With E_s connected to *ab* and the key closed, the contact *x* is shifted until a balance is obtained, when the galvanometer will read zero. Noting the value of r_s, the switch is thrown over to E_x, and the contact *x* again shifted until another balance is obtained, the new value of resistance, r_x, being noted. The value of the unknown potential difference is

$$E_x = \frac{E_s r_x}{r_s}$$

provided the current in the resistance *ab* remained constant.

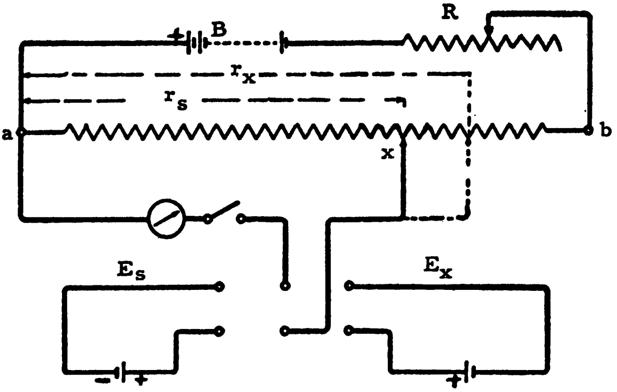


Fig. 12-9. Potentiometer Circuit Arrangement

If the rheostat, *R*, is so adjusted when balancing against the standard cell that balance is obtained with, for example,

$$\frac{E_s}{r_s} = \frac{1}{1000}$$

then $$E_x = \frac{r_x}{1000}$$

Thus, by making the drop across a certain definite resistance equal to one volt, the various subdivisions of the total resistance *ab* may be calibrated and marked in decimal parts of a volt, that is, 1.0, 0.1, 0.01, 0.001 volt, etc., so that the unknown potential difference can be read directly. This is the scheme usually employed.

It is to be noted that when balancing for E_x, it is immaterial whether the contact *x* is moved along *ab*, or the resistance between *a* and *x* is changed, provided that in the latter method a similar and opposite change is made between *x* and *b*, so that the total resistance *ab* remains constant.

Types

The usual classification of potentiometers is based on the value of the "potentiometer resistance," *ab*, Fig. 12-9; that is, whether it is *high* or *low*. A potentiometer with about 100 ohms or less total resistance is classified as low resistance, and one with a resistance of several hundred or several thousand ohms is classified as high resistance. The low resistance type is usually employed only in a measurement of very small potential differences in low resistance circuits, such as the emf from a thermocouple. A typical illustration of a precision potentiometer is shown in Fig. 12-10.

Another form of potentiometer, shown in Fig. 12-11, is the Brooks deflection type. In this type, an approximate balance is obtained in the usual manner. The unbalanced potential difference is shown by the deflection of the galvanometer, which has been previously calibrated. This deflection, converted to volts and added to or subtracted from the potential difference shown by the setting of the dials, gives the value of the unknown potential difference.

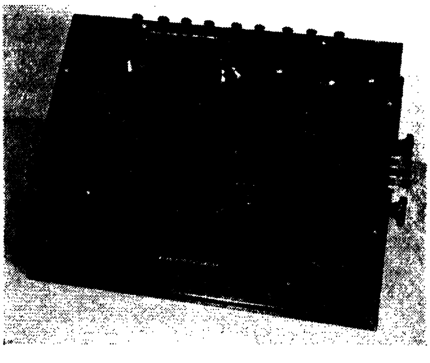


Fig. 12-10. Dial Type Potentiometer. New Pattern According to Recommendations of National Bureau of Standards (Leeds & Northrup Co.)

Fig. 12-11. Brooks Deflection Type Potentiometer (Leeds & Northrup Co.)

The application of the deflection potentiometer is found where the potential difference is not sufficiently steady to permit the use of the standard type of instrument, and where a higher precision than that obtainable with secondary standards (voltmeters, ammeters) is desired. The average of a slightly fluctuating potential difference can be readily estimated on the galvanometer. Where a great many determinations are to be made and speed is important, the deflection instrument is convenient.

Care and Use of Potentiometer Equipment

The secondary or auxiliary source of emf from which the potentiometer current is obtained is usually arranged to supply about two volts. A storage battery of one or two cells may be used with low resistance types where the current is relatively large. Dry cells are satisfactory for high resistance potentiometers and also for instruments of moderately low resistance if not in constant use.

The first trial for balance should always be made with a resistance in series with the galvanometer. This is usually provided in the instrument, with facilities for readily cutting it out of the circuit when the final balance is being obtained. The resistance protects the galvanometer and also the standard cell from the effects of excessive currents.

When not in use the instrument should be kept covered in order to keep the contacts free from dust.

Trouble is sometimes experienced, especially in damp weather, due to current "leaking to ground" from the potentiometer circuits, causing errors. This can be obviated by providing a "guard circuit." In one scheme of this kind all of the apparatus is placed on suitable insulators, each of which in turn rests on a small metal plate. These plates are connected together and to the positive binding post. Thus all points over the surface to which current might "leak" are kept at the highest external potential to which the potentiometer is connected.

In very precise measurements the potentiometer and volt box are placed in a shallow tank of special oil free from acids and sulphur, so that the coils are completely immersed. The oil is kept in motion and its temperature is held constant by a thermostatic control. For all ordinary measurements, that is, a precision of 0.02% or 0.03%, oil immersion is unnecessary if the apparatus has been designed for air cooling.

Calibration of Potentiometer

The calibration of a potentiometer consists of the determination of the ratio of the resistance of each step to the resistance between the standard cell terminals. This ratio should be the same as the ratio of the corresponding potential difference. In other words, it is essential that the various coils be equal, but not necessarily of any particular value. For example, if the standard cell emf is 1.0186 volt, and the resistance between its terminals is 101.86 ohms, the resistance of the various steps should be adjusted to 10 ohms per 0.1 volt. If the resistance between the standard cell terminals is 102.848 ohms, the potentiometer is still accurate if the resistance throughout the circuit is adjusted to 10.1 ohms per 0.1 volt. A potentiometer is checked, therefore, by measuring the resistance of the various steps and comparing the total at each setting with the resistance between the standard cell terminals. The deviation of this ratio from that of the corresponding potentials is the error that would be introduced in a measurement. Potentiometers are usually provided with facilities for conveniently measuring the resistance of each coil.

VOLT BOXES

As potentiometers are usually designed for a range of 1.5 volts, some form of multiplier is necessary for higher voltage measurements. A scheme often adopted is given in Fig. 12-12. The unknown voltage is impressed across a high resistance, generally 100 to 300 ohms per volt, and a voltage across a small portion of this resistance is supplied to the potentiometer. The ratio of resistances is such that full voltage on each range results in the application of 1.5 volts to the potentiometer. Volt boxes are commonly made with ranges of 15, 150, 300, 750, and sometimes 1500 volts.

Because of the very high resistance necessary in volt boxes for 100 volts and above, great care is necessary in their design in order to avoid leakage currents. As the average user has no opportunity of checking this point, the boxes should be purchased from a reliable maker of precision instruments.

Calibration of Volt Boxes

The ratios of the resistances of the various ranges in a volt box may be determined by passing a constant current through all of the coils, and measuring the drop of potential across each range by means of the potentiometer. Care must be taken not to exceed the capacity of the potentiometer. Where a standard resistance of 1000 ohms or so is available, the coils of the volt box may be checked by direct comparison with it.

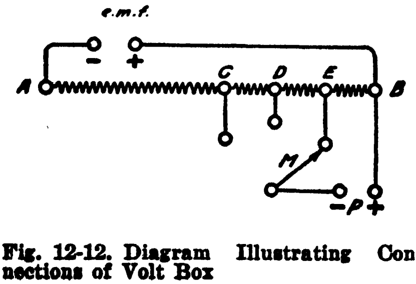


Fig. 12-12. Diagram Illustrating Connections of Volt Box

Measurements can be made more conveniently with a Wheatstone bridge. A five-dial precision Wheatstone bridge will detect errors to within 0.02 per cent.

GALVANOMETERS

A galvanometer is an instrument which indicates the flow of current, and it must be sufficiently sensitive to give a perceptible deflection when there is an unbalance equal to the smallest dial divisions of the apparatus with which it is used. To obtain this sensitivity a low resistance galvanometer of the order of 100 ohms should be used with a low resistance potentiometer; and a high resistance galvanometer of 500 to 1000 or more ohms, with a high resistance potentiometer.

SECONDARY STANDARDS

Direct Current

For direct-current work, secondary standards may consist of laboratory standard voltmeters and laboratory standard ammeters (or laboratory standard millivoltmeters with shunts), or of deflection type potentiometers. Indicating instruments used for this purpose should be of the D'Arsonval type, equipped with long legible scales. The scales, Fig. 12-13, are drawn with five equally spaced concentric arcs. Diagonal lines to facilitate reading are drawn from the top of each scale division to the bottom of the next division. The scales are provided with the usual mirrors for the elimination of errors due to parallax. When carefully set up in permanent positions and calibrated, these instruments are accurate to 0.1 of one scale division. They are of sufficient accuracy when carefully handled to serve as secondary standards for the checking of working standards.

Alternating Current

While many of the portable alternating-current working standards in use can be checked satisfactorily on direct current, there are some types of which this is not true. There are also numerous cases where test instruments should be verified on alternating current under the same conditions as those under which they are used. Therefore, some form of "transfer instrument" is necessary as a secondary standard. It is always some form of electrodynamometer.

An electrodynamic instrument derives its torque from the reaction between a movable and a fixed coil as shown in Fig. 12-14.

A modern electrodynamometer is shown in Fig. 12-15. Instruments of this type are available as voltmeters, ammeters and wattmeters. They can be obtained with a guarantee that the errors will not exceed 0.1% of full scale value for frequencies from 15 to 133 cycles. They are equally accurate on direct current, provided reversed readings are taken and the average values used. These instruments are provided with scales similar to that shown in Fig. 12-13. They are shielded from the effects of external magnetic fields.

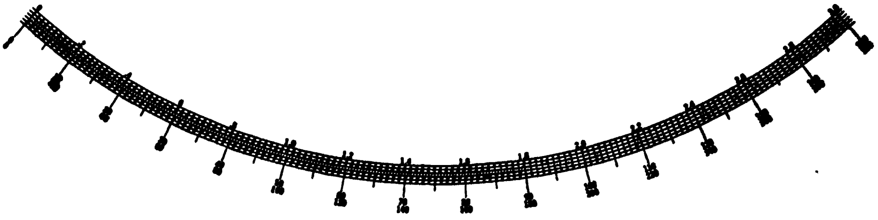


Fig. 12-13. Model 5 Voltmeter Scale (Weston Electrical Instrument Corp.)

A multi-range current transformer extends the range of laboratory standard instruments without appreciable change in accuracy, provided ratio and phase angle corrections are applied.

Periodic Certification

In addition to periodic complete checks throughout the working range, frequent abbreviated checks with pri-

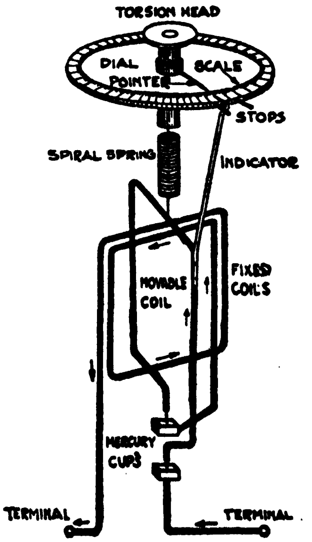


Fig. 12-14. Arrangement of Coils of Dynamometer

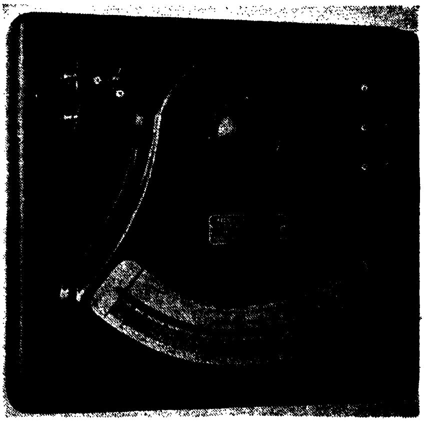


Fig. 12-15. Laboratory Standard A-C Ammeter-Wattmeter (General Electric Co.)

mary standards should be made. This abbreviated check should consist of verification of zero and a check of one point above half scale on every range of the instrument.

INSTRUMENTS FOR MEASURING RESISTANCE

In the laboratory, resistances are usually measured by bridge methods. Bridge methods are the most accurate for resistance measurements because they are null methods. The comparison is made directly with standardized resistors.

The principle on which the Wheatstone bridge operates may be explained as follows:

Fig. 12-16 shows the theoretical arrangement of a Wheatstone bridge where R, R_1 and R_2 are accurately known resistances, and R_x is the resistance to be measured. When using the bridge, the various resistances are adjusted until the galvanometer, G, shows no current flowing:

then

$$R_x = \frac{R_2}{R_1} R$$

The battery switch, S_1, should always be closed before the galvanometer switch, S_2, and should be opened after the latter to prevent an inductive kick which would result if the battery switch S_1 were opened while the galvanometer switch S_2 is closed. The design of the apparatus sometimes includes a device which automatically insures this procedure. The galvanometer and the battery may be interchanged, depending on the relative value of the several resistances.

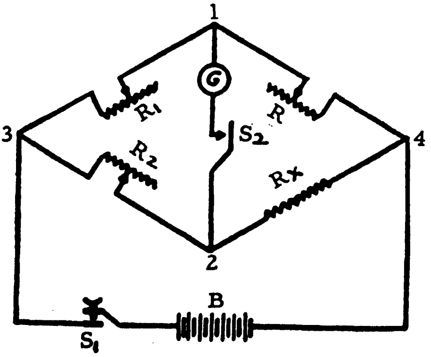


Fig. 12-16. Wheatstone Bridge, Circuit Arrangement

The Wheatstone bridge is, in general, suited to measuring resistances from about 1 to 100,000 ohms. If the unknown resistance is intermediate in value between the limits stated, errors to be expected with a first-class bridge are of the order of 0.01 to 0.05 per cent. It is to be noted, however, that a very high precision may be obtained with the simple Wheatstone bridge where the resistances of the arms are favorably chosen. With a galvanometer of sufficient sensitivity, measurements may be made to 1 part in 1,000,000 by shunting one or two arms. The sensitivity of the bridge becomes higher when the four arms are equal; hence this condition should always be approached as nearly as possible by keeping R_1/R_2 near unity, and R_1 and R_2 as nearly equal to R as convenient.

Another form of bridge especially suitable for measuring low resistance of the order 0.000001 to 10 ohms, is the Thomson bridge. The principle is shown in Fig. 12-17. When a balance is obtained, if the resistance of the connections to the bridge be neglected:

$$\frac{r_x}{r} = \frac{r_1}{r_2} + \frac{d}{r}\left(\frac{b}{a + b + d}\right)\left(\frac{r_1}{r_2} - \frac{a}{b}\right)$$

where the symbols represent the values of the resistances indicated. If $r_1/r_2 = a/b$, the expression following the addition sign (called the corrective term) becomes zero and $r_x = r\frac{r_1}{r_2}$, as in the Wheatstone bridge. In practice, therefore, the ratio r_1/r_2 is kept as nearly equal to the ratio a/b as possible, and the connecting resistance d is made as small as possible.

If the connecting resistance, d, is removed, the network of conductors becomes a Wheatstone bridge in which, at balance,

$$\frac{r_1}{r_2} = \frac{r_x + a}{r + b}$$

Therefore, a test for equality of the

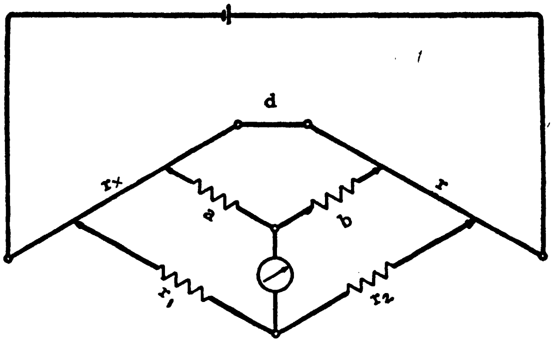


Fig. 12-17. Kelvin (Thomson) Bridge, Circuit Arrangement

ratios r_1/r_2 and a/b may be made as follows:

After a double-bridge balance has been obtained, the resistance d should be removed, and if the bridge is still balanced, the ratio r_1/r_2 will be very nearly equal to the ratio a/b because r_x and r will always be very low resistances compared with a and b, and, furthermore, they are always in the same ratio. Consequently, it may generally be assumed without error that $r_1/r_2 = r_x/r$. If the bridge is not found balanced after removal of d, it may be balanced by adjusting either a or b until an exact balance is obtained. A typical double bridge is shown in Fig. 12-18.

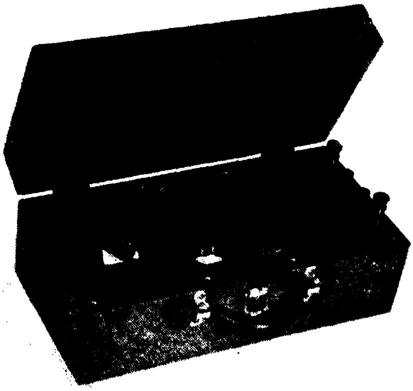


Fig. 12-18. Kelvin Double Bridge (Leeds & Northrup Co.)

Galvanometers for use with bridges are similar to those used with potentiometers. When very high accuracy is not required, a bridge with a built-in galvanometer is suitable.

For the Wheatstone bridge the voltage source may be dry cells. Resistances measured by means of the double bridge are generally of higher current carrying capacity and the use of storage batteries is desirable.

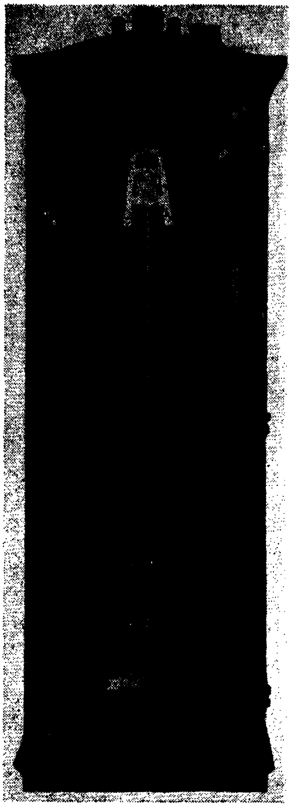
The bridge tops and all connections should be kept clean at all times, as dust, finger marks, etc., may cause serious leakage. With some forms of bridge it is difficult, when the humidity is high, to make accurate measurements of high resistance owing to the film of moisture that clings to the surface.

A properly designed and maintained bridge should keep its initial accuracy almost indefinitely.

HOROLOGICAL STANDARDS

Standard time can be obtained by the use of radio apparatus for receiving the time signals broadcast by the Government or by time signals from telegraph companies. The use of the radio receiving equipment is obviously more direct and in general more satisfactory.

A standard seconds pendulum clock, with its time regulated by checking daily against standard time, is an effective way of obtaining a source of standard seconds. Some form of de-



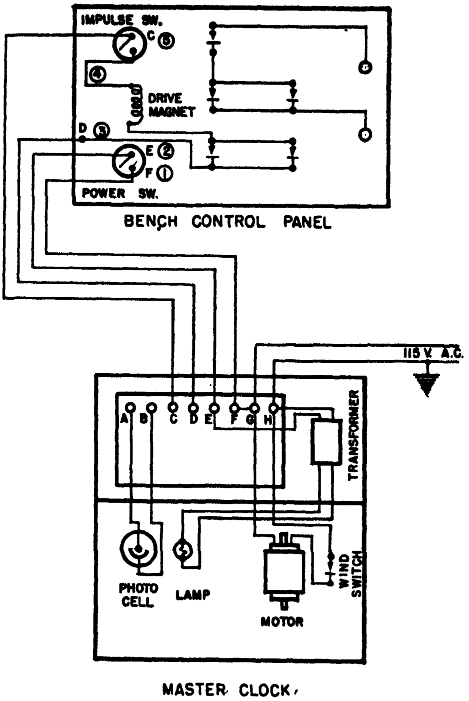


Fig. 12-19. Interior of Standard Clock with Photo-electric Impulse Pick-up Equipment and Schematic Diagram for the Clock (Standard Electric Time Co.)

vice affixed to the pendulum can be arranged to give a signal at intervals of a second. The swing of the pendulum or the second hand may be observed for the second intervals.

Photoelectric cell equipment is also available for transmitting the beats of the pendulum of such a clock; and through auxiliary equipment, time intervals of the desired duration may be obtained readily. Fig. 12-19 shows one form of such equipment.

Synchronous Timers

These devices are essentially synchronous clocks that can be started and stopped at will and provide a ready means for checking the accuracy of frequency recorders and indicators and constant frequency control apparatus. By comparing the timer indication with the indication of an accurate watch or clock, the average frequency during a given time interval can be determined readily. Fig. 12-20 shows one form of a device of this character. A magnetic clutch and convenient push-button switch provide the means of starting and stopping. The device may also be used to measure time intervals for the calibration of time delay relays and similar apparatus.

A similar device for these purposes is the so-called cycle counter. It consists of an escapement driven set of dials, the escapement being actuated by a type of electromagnet which vibrates in synchronism with the frequency of the source from which it is energized. Thus the escapement counts the cycles during the interval it is energized. It is usually arranged to be started and stopped by an auxiliary relay which may also be used to control the equipment under test.

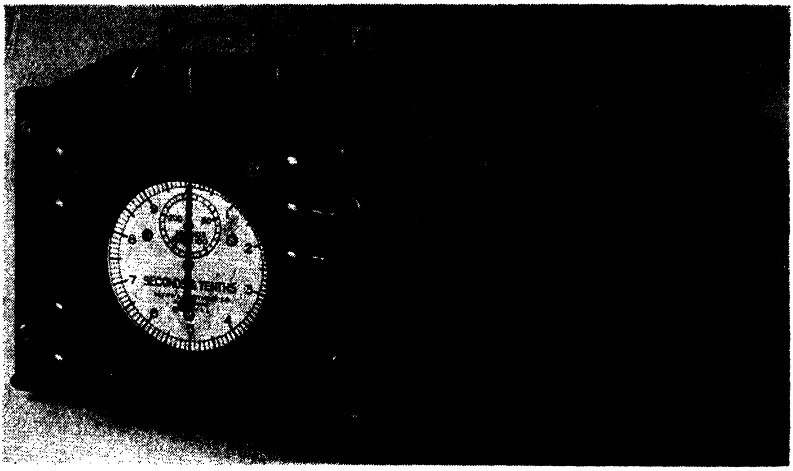


Fig. 12-20. Synchronous Timer (Leeds & Northrup Co.)

An electrically operated tuning fork is also recognized as having characteristics which make it particularly suitable for the basis of an accurate timing device.

Chronographs

Chronographs are instruments constructed to measure small increments of time. In the usual forms, the record paper is placed on the surface of a drum which is driven at a constant speed.

PORTABLE WORKING STANDARDS

Direct-Current Instruments

All of the instruments considered here for use on direct current only are of the D'Arsonval principle. Fig. 12-21 shows the essential features which are common to all makes. They are available in voltmeters, millivoltmeters and ammeters.

Current is led in over one spring to the winding and out over the other spring. The armature is free to rotate about the axis of its pivots through approximately 90 degrees. If the instrument is used in locations where there are strong magnetic fields, as in the neighborhood of feeders or bus bars, its accuracy may be affected. If the field is relatively weak, the error will be temporary, as no loss of permanent magnetization results. If the field is strong enough, it may demagnetize the magnet to a large extent, resulting in permanent errors. To eliminate ordinary trouble from this source, some instruments are enclosed in iron cases which act as shunts for stray magnetic fields. The safe course is to use at all times instruments that are shielded.

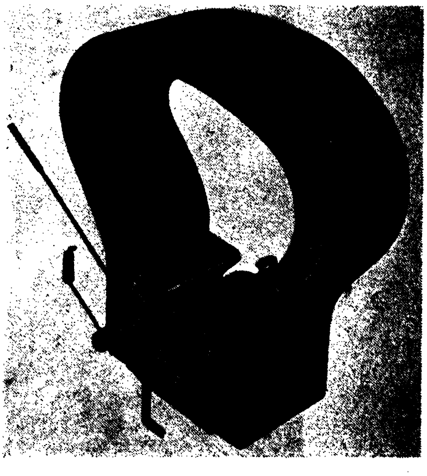


Fig. 12-21. D-C Movable System (Weston Electrical Instrument Corp.)

Alternating-Current Instruments

The available portable test instruments for alternating-current service may be divided into three classes; the electrodynamometer, the inclined coil, and the induction types. Instruments based on other principles are available, but the accuracy obtainable commercially is not sufficient to include them in this description. In general, test instruments of the electrodynamometer type are perhaps the most satisfactory.

The design must be such as to minimize errors from temperature, wave form, frequency, and in the case of the wattmeter, power factor changes. In the better grade of instruments, such errors are very small for all commercial ranges of frequency and wave form. An instrument of this type may be checked on direct current, provided reversed readings are taken and their average values used as a true indication. The corrections thus obtained can also be applied where the instrument is used on alternating current. A wattmeter is made that compensates for its own loss, so that it may be used for measuring losses of apparatus without the need of correcting it for the loss in its potential circuit.

Alternating-current instruments of the inclined coil type are made as ammeters and, in some cases, as voltmeters. Fig. 12-22. This type is not suitable for use on direct current. For the standardization of instruments of this kind, some form of transfer instrument such as an electrodynamometer must be used.

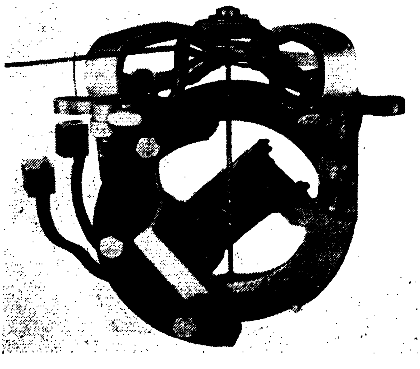


Fig. 12-22. Element for Type P-3 Ammeter (General Electric Co.)

Induction type instruments are strictly for alternating-current use. They are somewhat subject to frequency and wave form errors, but are not so susceptible to stray field effects if unshielded as the two preceding types.

Periodic Certification

In addition to periodic complete checks throughout the working range, frequent abbreviated checks with secondary standards should be made. This abbreviated check should consist of verification of zero and a check at one point above half scale on every range of the instrument.

PRECISION TEST EQUIPMENT FOR CURRENT AND POTENTIAL TRANSFORMERS

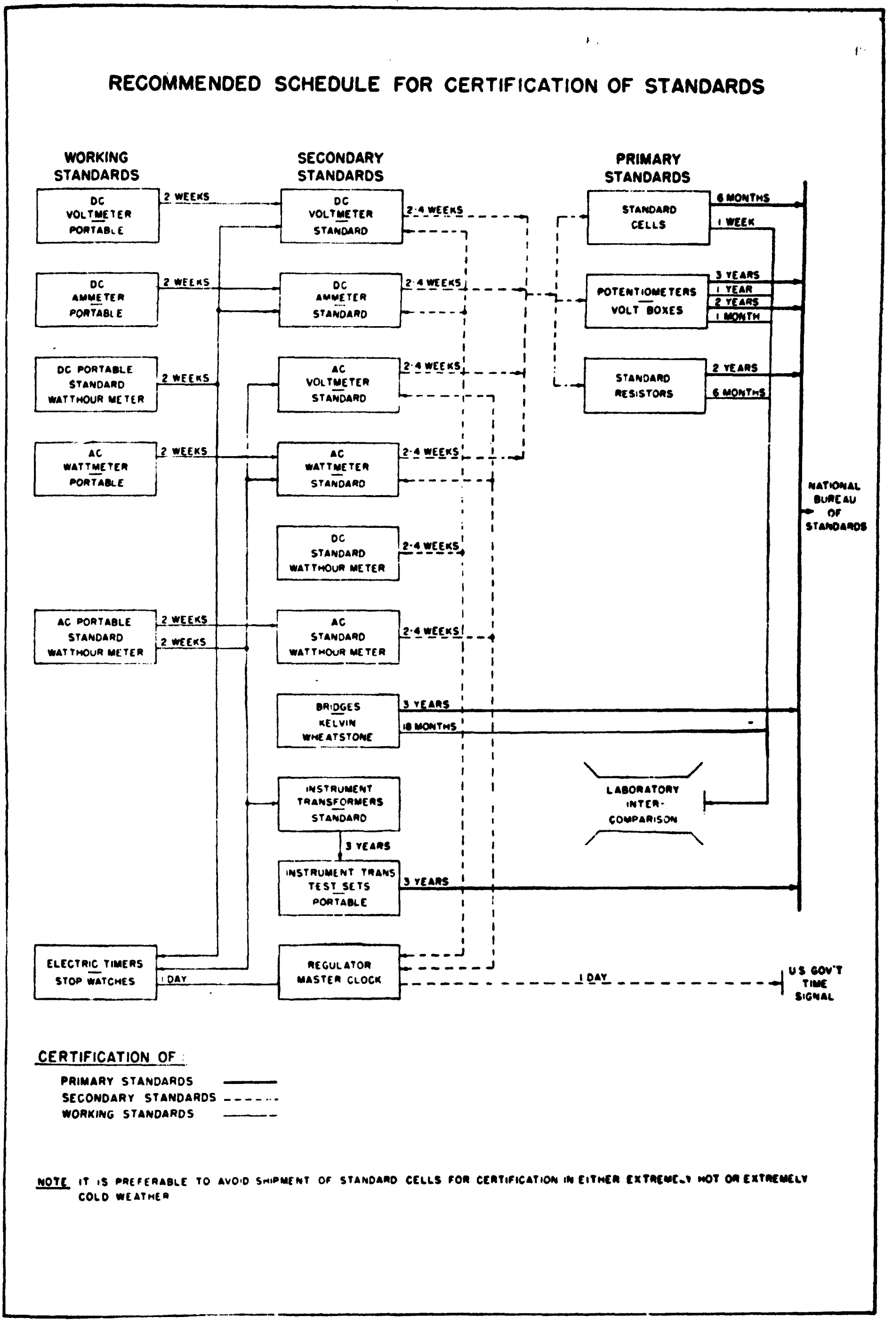
This test equipment is fully described in Section 5 of this Handbook.

RECOMMENDED SCHEDULE FOR CERTIFICATION OF STANDARDS

A recommended periodic schedule for the certification of standards is given in Fig. 12-23. This schedule is based on the recommendations contained in the *Code for Electricity Meters,* Fourth Edition. In those cases where a range of time is given, the actual schedule selected will depend upon the frequency of use of these standards.

Also in certain cases, abbreviated test checks may be made at the intervals given and complete checks throughout the working range at less frequent intervals. In many cases, it may be necessary to reduce the recommended minimum period because of the requirements of authorities having jurisdiction.

In addition to the periodic certification, it should be verified whenever the standard appears to be erratic, or if it has been subjected to possible damage or to any abnormal effect which might cause a change in its electrical values.



NOTE: IT IS PREFERABLE TO AVOID SHIPMENT OF STANDARD CELLS FOR CERTIFICATION IN EITHER EXTREMELY HOT OR EXTREMELY COLD WEATHER

Fig. 12-23. Recommended Schedule for Certification of Standards

MISCELLANEOUS TEST INSTRUMENTS, A-C AND D-C

A number of test instruments, special devices, etc., are described in the following paragraphs.

Power Factor Meters

A power factor meter is an instrument which indicates or records directly the power factor of an alternating-current circuit. The pointer moves over a graduated scale, marked so as to read either phase difference in degrees or power factor. Meters are available for use on single-phase and polyphase circuits.

There are two general classes: those involving the principle of the electrodynamometer and those based on the principle of the induction wattmeter.

Electrodynamometer Type—The essential feature of a single-phase power factor meter operating on this principle is shown in the diagram, Fig. 12-24.

The polyphase meter is shown in Fig. 12-25. There are two or three coils in the moving system, one connected across each phase. The principle of operation is exactly the same as in the single-phase instrument, the moving system taking up a position where the resultant of the torques will be a minimum, which position will vary with the power factor of the circuit on a balanced polyphase load.

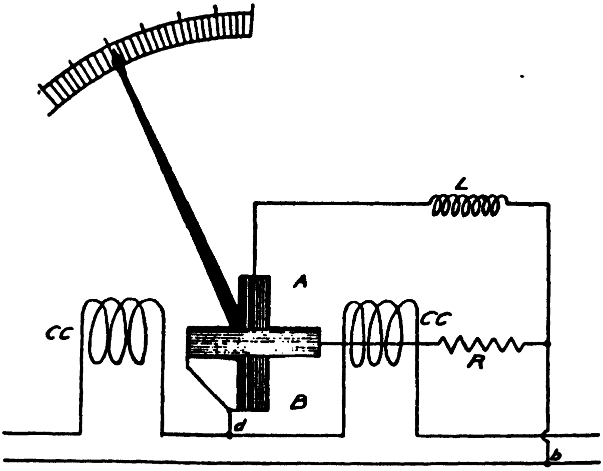


Fig. 12-24. Diagram of Moving-coil Type of Single-phase Power Factor Meter

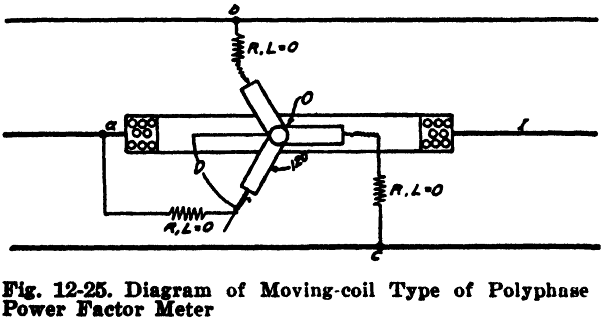


Fig. 12-25. Diagram of Moving-coil Type of Polyphase Power Factor Meter

Induction Type—In one type of single-phase induction power factor meter, the fixed element consists of three stationary coils, and the moving element comprises an iron armature, to the shaft of which an indicator is attached. As in the electrodynamometer type the operation is based on the interaction of a rotating and an alternating magnetic field. One type is shown in Fig. 12-26.

Use and Calibration—Polyphase instruments having but one current coil are not dependable for measurements of power factors where voltage and currents are unbalanced. Where three current coils are used, the meter gives an average value of the power factor in the three phases.

Power factor meters can be checked and calibrated by means of indicating instruments with the aid of a phase-shifting device. Where this method is employed, the power factor is given by the ratio of the reading of the wattmeter to the product of volts and amperes.

Where a polyphase source is available, two wattmeters may be used for testing by connecting one wattmeter as a reactive volt-ampere meter. The ratio of the wattless component to the power component gives the tangent of the angle whose cosine is the power factor.

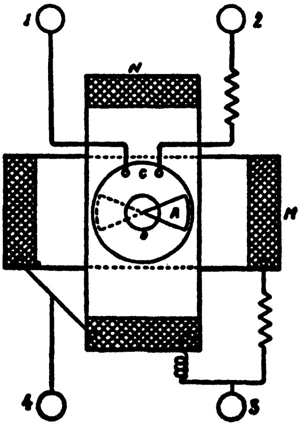


Fig. 12-26. Diagram of Induction Type of Power Factor Meter

Frequency Meters

A frequency meter is an instrument designed to indicate or record the number of cycles per second of an alternating-current circuit. They are in general based upon two distinct principles in their construction.

Resonance Frequency Type—Strips of metal, usually steel, are fastened at one end, with the other end free, in much the same way as the reeds of an organ. These strips have different periods of free vibration and can be made to vibrate by outside impulses whose frequencies are the same. The impulses in these instruments are magnetic and are supplied by an alternating current flowing in an electromagnet connected to the circuit whose frequency is to be determined. If the reed is tuned to vibrate with twice the frequency of the alternating current, it will be set in vibration as it is attracted at each alternation and released each time the current passes through zero. If the natural period of the reed is not in synchronism with that of the alternating-current circuit, the impulses will, during a part of each cycle, occur so as to oppose the motion of the reed and the amplitude will thus be retarded. Slight variation from the critical condition will result in a very noticeable diminution of the amplitude of the reed so that close readings are possible.

Other Types—Some of the other types of frequency meters are based upon the action upon each other of two circuits having different impedances which are connected in multiple to the alternating-current circuit to be measured. In the induction type, two voltmeter movements are connected so as to tend to rotate a disk in opposite directions. One of these is connected in series with a resistance and the other with an inductance. The impedance of the circuit of the inductive movement varies with the frequency, thus varying the amount of current taken by it. The impedance of the non-inductive movement remains the same with changes in frequency. The interaction of the two elements will then cause the pointer to take up a differ-

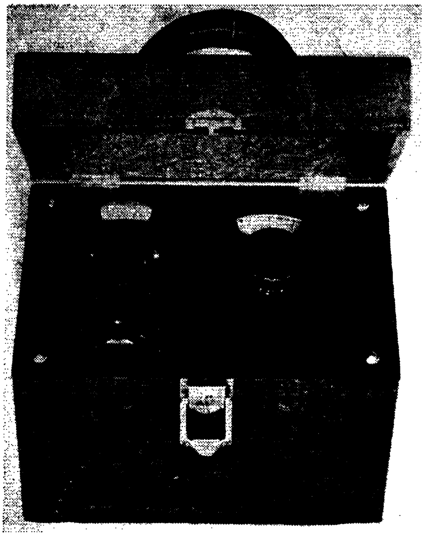


Fig. 12-27. Null Type (Impedance) Frequency Indicator (Leeds & Northrup Co.)

ent position on the scale for each change in frequency. Another type of frequency meter is based upon the impedance bridge principle. A detecting galvanometer in the bridge circuit is automatically balanced by a change in the impedance values after each variation in frequency. These changes in impedance are then measured by a potentiometer in terms of frequency. Fig. 12-27.

Ohmmeters

Ohmmeters are instruments which indicate resistance in ohms directly. They are useful where measurements are to be made rapidly with a moderate degree of accuracy.

Ohmmeters are manufactured in two classes. In one class the resistance is indicated by a pointer moving over a calibrated scale and in the other class the principle of the slide-wire bridge is employed.

The deflection or pointer type instruments are usually constructed along the lines of a voltmeter and can be used for the measurement of both moderate and high resistances. They are usually operated by means of dry cells although in some types a hand-driven generator is used. Several portable types of meters are shown in Fig. 12-28.

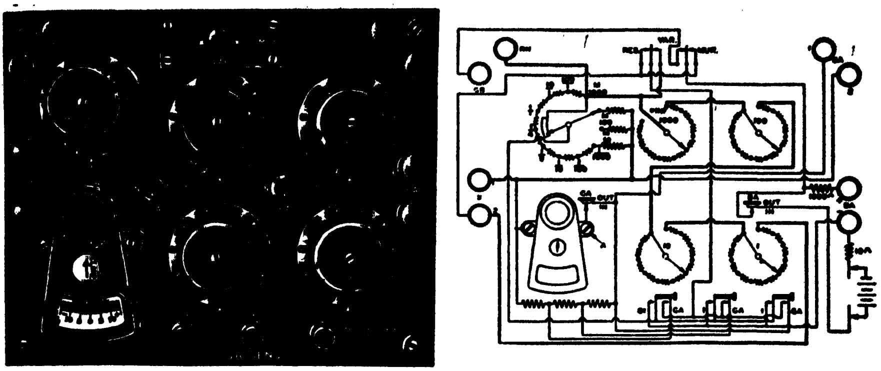
The bridge types of ohmmeters are suitable for moderate resistance measurements. In general, ohmmeters of the bridge type may be operated with a higher degree of precision than those of the deflection type.

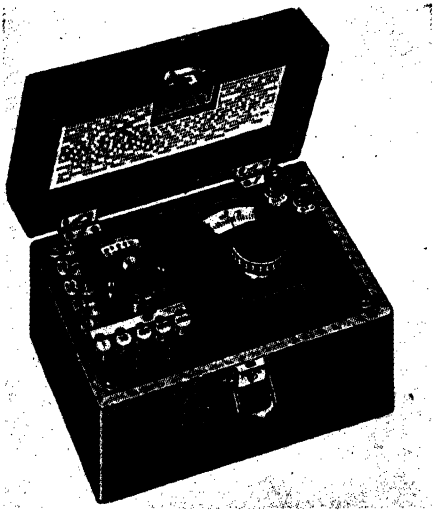
Oscillograph

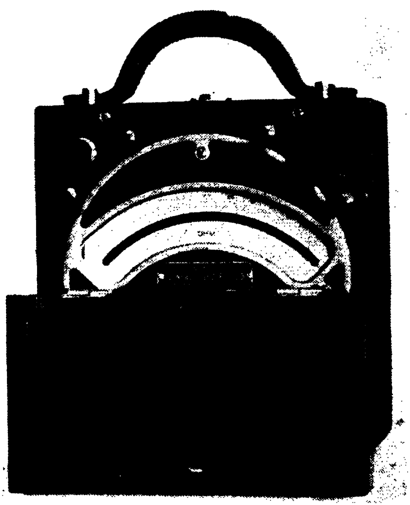
The oscillograph is an instrument designed for producing a continuous curve representing the instantaneous values of a rapidly varying electrical quantity. It is one of the most versatile instruments developed for observing the characteristics and behavior of electrical phenomena. It is commercially available in two forms—the magnetic oscillograph, and the cathode-ray oscillograph tube.

The magnetic oscillograph consists essentially of a special form of mirror galvanometer with an associated optical system so arranged that the light beam impinges on a photosensitive chart moving at a constant rate. In the case of transient phenomena, it is often necessary to arrange special devices to start the film automatically at the proper time to get the phenomena on the film. Fig. 12-29 shows a typical optical system of the oscillograph. Fig. 12-30 shows a typical oscillogram made with a multiple element oscillograph. In some instances it is desirable to observe the wave shape as well as to record it. To accomplish this, the oscillograph is equipped with a viewing system consisting of a revolving multi-faced mirror which reflects the light beam to a curved viewing screen whose entire surface is in the focal plane of the film. Fig. 12-31 shows a visual type oscillograph.

In the cathode-ray oscillograph tube, the deflection of an electron beam indicates the instantaneous values of the actuating current or voltage. Instantaneous values of any quantity which can be converted into an electrical potential, which varies according to the variations of the quantity to be measured, can be plotted on the fluorescent screen. Since the electron beam has negligible inertia, the tube may be used to plot rapidly changing quantities







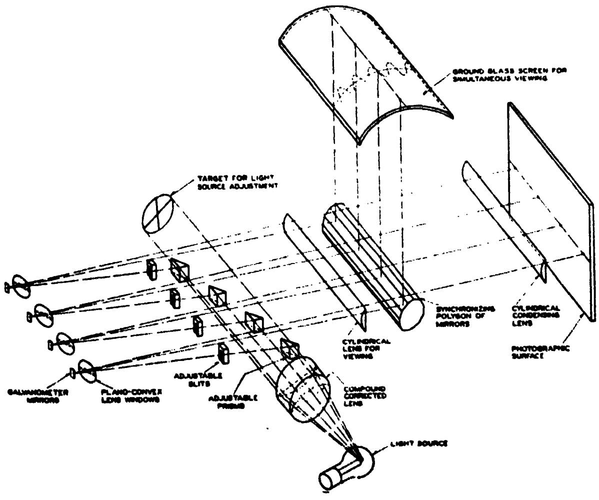

GROUND GLASS SCREEN FOR SIMULTANEOUS VIEWING
TARGET FOR LIGHT SOURCE ADJUSTMENT
SYNCHRONIZING POLYGON OF MIRRORS
CYLINDRICAL CONDENSING LENS
CYLINDRICAL LENS FOR VIEWING
PHOTOGRAPHIC SURFACE
ADJUSTABLE SLITS
GALVANOMETER MIRRORS
PLANO-CONVEX LENS WINDOWS
ADJUSTABLE PRISMS
COMPOUND CORRECTED LENS
LIGHT SOURCE

Fig. 12-28. Ohmmeters

(*Top*) Wheatstone Bridge Type for Cable Fault Location by Murray and Varley Loop Methods (Leeds and Northrup Co.)

(*Center Left*) Slide Wire Type (Leeds & Northrup Co.). (*Center Right*) Indicating Type (General Electric Co.)

Fig. 12-29. (*left*) Typical Optical System of an Oscillograph

Fig. 12-30. Typical Oscillogram

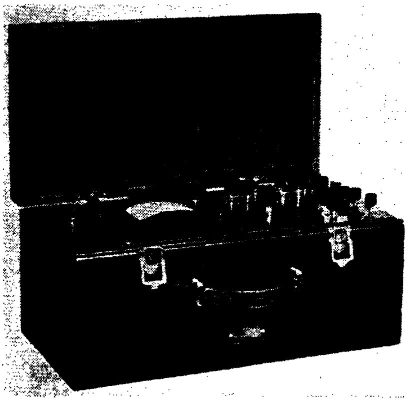


Fig. 12-31. Visual Type Oscillograph (General Electric Co.)

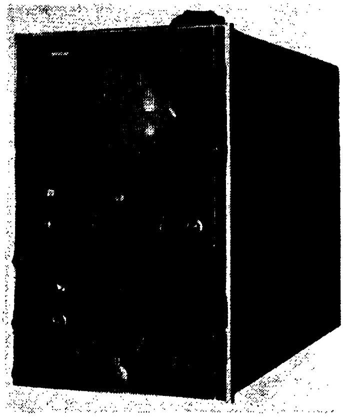


Fig. 12-32. Cathode Ray Oscillograph (Allen B. Dumont Laboratories, Inc.)

which cannot be plotted with a mechanical system of indication. Another advantage of the electron beam type of indicator is that it cannot be damaged by application of over-voltage. Furthermore, the indicator requires a negligible amount of power for operation. Thus, the source of the phenomena under observation is not burdened with a load which might disturb its operating characteristics. Fig. 12-32 illustrates a cathode-ray oscillograph and Fig. 12-33 illustrates an oscilloscope using a cathode-ray oscillograph tube.

Photoelectric Cell Type Recorders

The basic measuring element in the photoelectric cell recorder may be any type of deflection instrument or a sensitive galvanometer. A light beam is reflected by a mirror on the basic measuring element into an optical system which in turn directs it to either or both of two photo-electric cells. The current from the cells is amplified and made to drive a recording pen either up or down the scale of the chart as the case may be, depending upon the position of the measuring element. When the recording pen reaches the equivalent position of the measuring element it is brought to rest. The response of the instrument is fast and sensitive and quite accurate. Figs. 12-34, 12-35, and 12-36 show the recorder and a diagram of the optical system.

Potentiometer Type Recorders

The potentiometer type recorder operates on the null principle and uses

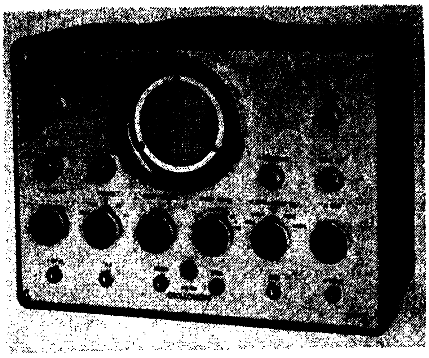


Fig. 12-33. Oscilloscope Using Cathode Ray Oscillograph Tube (Radio Corporation of America)

a sensitive galvanometer as the basic measuring element. When the galvanometer deflects in either direction from normal, a mechanical linkage is set in motion which operates a set of potentiometer resistances in such a way as to provide a back potential to just balance the potential being measured, thus returning the galvanometer to normal position again. At the same time a recording pen is driven to a position on the chart that coincides with the value of the quantity being measured. Calibration is effected by balance against a standard cell. Fig. 12-37 shows one form of this type recorder.

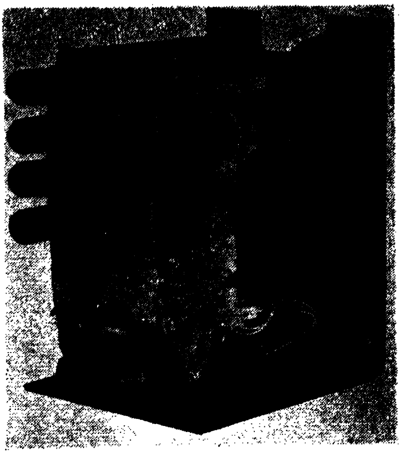


Fig. 12-34. Photo-electric Recording Frequency Meter Having Auxiliary Pen (General Electric Co.)

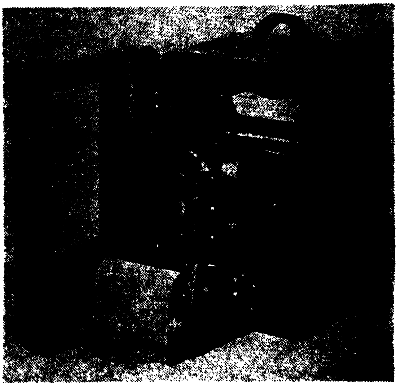


Fig. 12-35. Photo-electric Cell Type Recorder

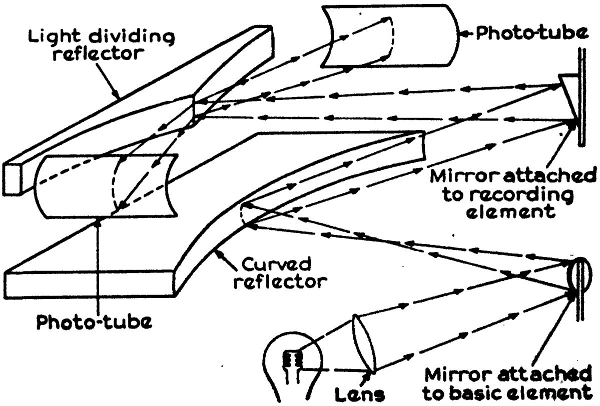

Light dividing reflector
Photo-tube
Mirror attached to recording element
Curved reflector
Photo-tube
Lens
Mirror attached to basic element

Fig. 12-36. Optical System of Photo-electric Cell Type Recorder

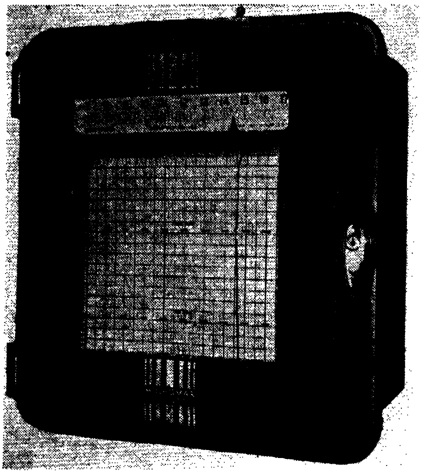


Fig. 12-37. Potentiometer Recorder (Leeds & Northrup Co.)

Temperature Indicators and Recorders

Temperature measurements are obtained by several different devices, the more common of which are as follows:

1. Thermometers, expansible liquid, gas and thermal strip types
2. Resistors (exploring coils), change of electrical resistance with temperature, Fig. 12-38
3. Thermocouples
4. Optical pyrometers

The last three types depend principally on electrical measurement for their operation. The resistance thermometer type indicating or recording instruments operate on the Wheatstone bridge principle. The thermometer detectors are usually made of coils of copper, nickel or platinum wire which are very carefully calibrated.

The thermocouple method depends upon the fact that the junction of two dissimilar metals produces by galvanic action an emf proportional to temperature. If two such couples are differentially connected in series and one held at a known temperature (called the cold junction), the other held at the temperature to be measured, then the potential difference between the two couples will give a measure of the difference in the two temperatures. This potential difference is generally measured by a potentiometer indicator or recorder such as is shown in Fig. 12-37, and the instrument is usually calibrated to read temperature direct with a definite type of thermocouple.

Optical pyrometers operate on the principle of balancing the light from a hot body of unknown temperature against that from a body of known temperature and therefore are only used for measuring high temperatures where the material is heated to incandescence. The known temperature is generally determined by the light intensity of an incandescent lamp filament which has been carefully calibrated in terms of filament current. A measurement of this current is then a measure of temperature. Fig. 12-39 shows a device of this type.

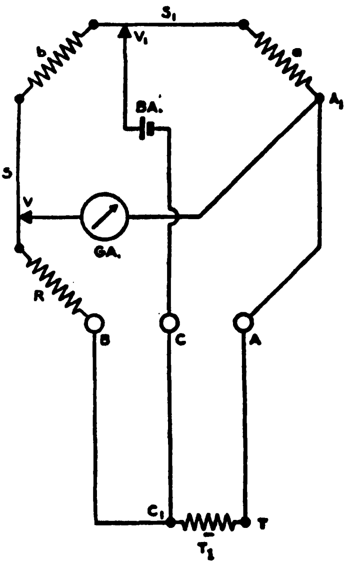


Fig. 12-38. Diagram of Resistance Type of Measuring Equipment

The resistance thermometer T_1 has three leads, AT, BC_1 and CC_1 and if the resistance $AT = BC_1$, the length of the leads has no effect upon the accuracy.

These instruments are made in switchboard, portable and recording types.

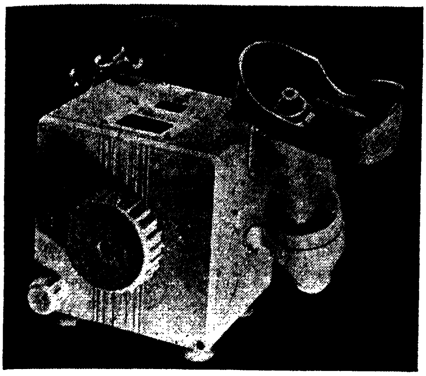


Fig. 12-39. Optical Pyrometer (Leeds & Northrup Co.)

Phase Shifters, Laboratory Types

Phase shifters are used for the purpose of obtaining the desired phase relation between the current and voltage. One type of phase shifting transformer is shown in Fig. 12-40. This transformer consists of stator and rotor elements of laminated steel, each being wound with a three-phase winding. The rotor may be turned through an angle of three hundred and sixty mechanical degrees and locked at any position. An index dial, attached to the rotor, moves adjacent to a stationary scale which is calibrated in electrical degrees. The index plate indicates the cosines of the electrical angle through which the rotor is shifted. This permits the direct reading of both the electrical angle of displacement between primary and secondary and the power factor corresponding to this angle. With this device any desired power factor, either leading or lagging, may be obtained on a three-phase circuit; the adjustment obtained with this phase shifter is continuous. It is suitable for polyphase meter testing, the calibration of power factor meters, experimental work and laboratory research. Fig. 12-41 shows a portable type of induction phase shifter.

Fig. 12-42 shows diagrammatically the operation of a polyphase phase shifter. The solid lines indicate the relative position of the primary and secondary coils for unity power factor. The dotted lines show the relative positions of the reference point "A" for power factors of 0.5 and zero, both in a lagging and leading direction. The outer arrow indicates the direction of rotation of the magnetic field.

Another type of phase shifter for use in meter testing is shown in Fig. 12-43. This is the tapped autotransformer type. The dial is marked in

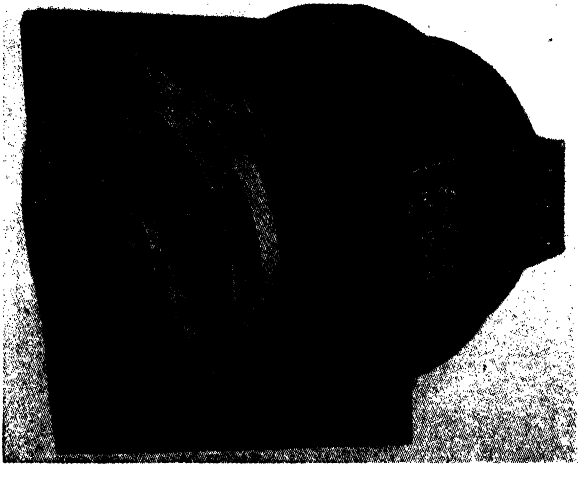


Fig. 12-40. Switchboard Type Phase Shifting Transformer (The States Co.)

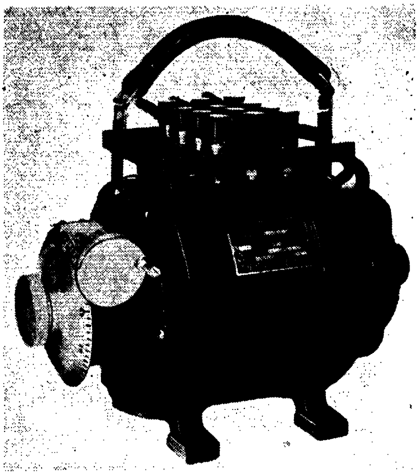


Fig. 12-41. Potential Phase Shifter (The States Co.)

terms of power factors corresponding to the phase displacement. This is a "step-by-step" phase shifter, and the adjustment is not continuous as in the case of the type previously described. Fig. 12-44 shows a portable autotransformer type.

Induction Regulators

Induction regulators are particularly designed for maintaining definite values of current or voltage during tests or comparison checks on alternating-current measuring instruments. Current drawn from this type of regulator generally has badly distorted wave form when the rotor is near its maximum bucking position.

A stator and rotor type is shown in Fig. 12-45. This type is similar in

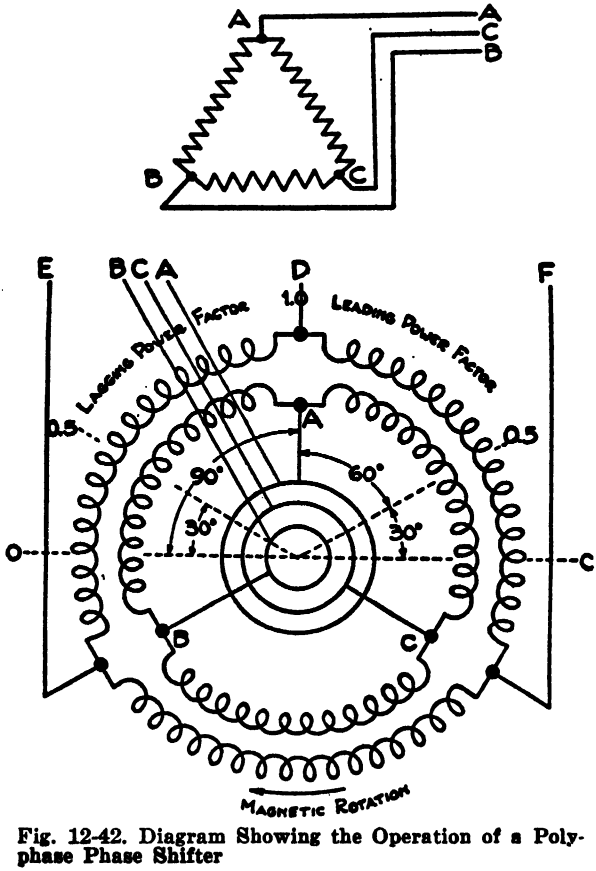


Fig. 12-42. Diagram Showing the Operation of a Polyphase Phase Shifter

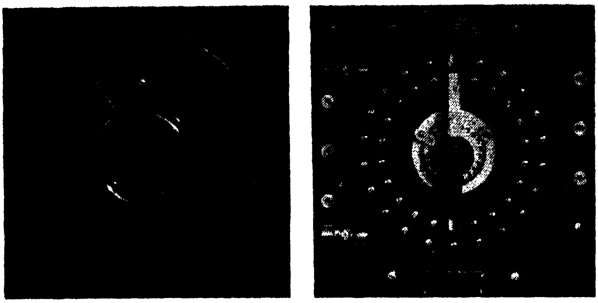


Fig. 12-43. Potential Phase Shifter—Front and Rear Views (The States Co.)

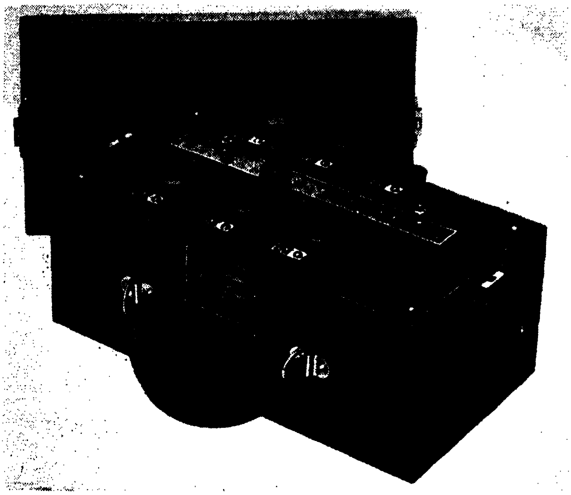


Fig. 12-44. Portable Potential Phase Shifter (The States Co.)

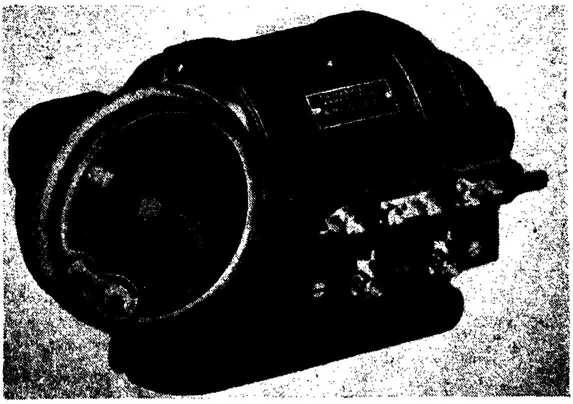


Fig. 12-45. Induction Type Regulator (The States Co.)

appearance and construction to a small motor, in that it has a stator and rotor. On the stator is a primary winding which may be connected to a source of constant voltage. On the rotor is a secondary winding in which a voltage will be induced, varying in value from zero to a maximum, depending upon the position of the movable part. A small hand wheel serves to turn the rotor and enables the operator to adjust the current or voltage as desired.

Other convenient types of voltage regulators are shown in Figs. 12-46 and 12-47. Each consists of a single-layer winding on a torus ring core arranged with a rotary brush mechanism which, by rotating, can be made to contact each turn of the transformer as desired, thus varying the voltage from zero to the maximum.

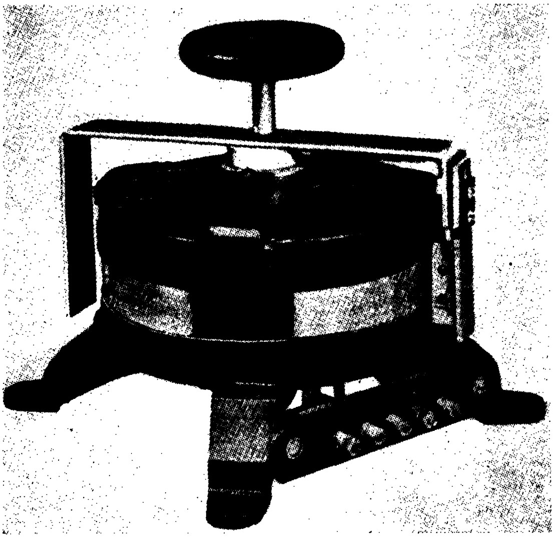


Fig. 12-46. Adjustable Transformer for Obtaining Various Values of Voltage, Cover Removed (American Transformer Co.)

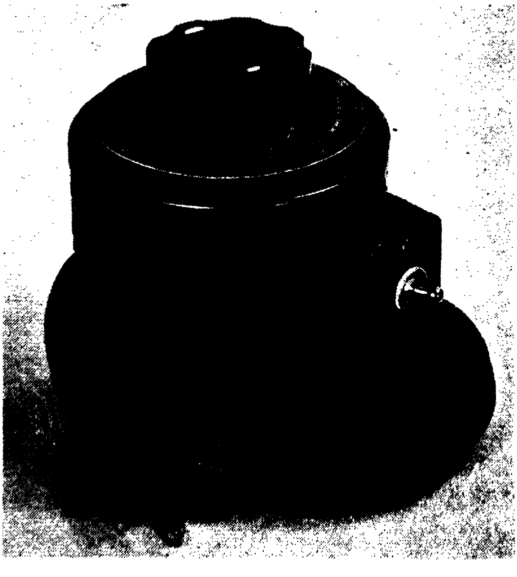


Fig. 12-47. Adjustable Transformer for Obtaining Various Values of Voltage (General Radio Co.)

SECTION 13

DUNCAN ELECTRIC MANUFACTURING COMPANY METERS

The following descriptive material pertains to types of meters placed in production since 1924 by the Duncan Electric Manufacturing Company. Information on other direct- and alternating-current types may be found in the appendix and previous editions of the *Electrical Metermen's Handbook*. Detailed data and constants, however, are included for all types.

Only salient features and major changes in meters are described. More detailed information concerning the meter types may be obtained from the manufacturer's published material.

ALTERNATING-CURRENT WATTHOUR METERS

Type MD Watthour Meters

This line of single-phase and polyphase meters was manufactured from 1926 to 1934 when superseded by the MF line. During 1929 and 1930, a number of major changes were incorporated in meters above serial no. 1,300,000. The principal changes were the addition of temperature and overload compensation and the changing of the inductive load adjustment from a phasing plate to a closed-circuit coil.

All ratings up to and including 50 amperes were designed to carry 300% of rated current continuously without exceeding 40 C rise in the coils or terminals.

Type MD—Single Phase—The type MD meter superseded the type M2 which it resembled in construction and adjustments. A cast-iron base was used, the general arrangement and dimensions being similar to present-day single-phase meters. A studless glass cover, held by bayonet joints, was introduced in 1929.

Type MD—Two-Element Network—This meter has two electromagnets, each similar to the type MD single-phase, which are mounted with two disks in vertical tandem on a single shaft. The terminal arrangement and dimensions of the terminal chamber are similar to the type MD single-phase; the overall dimensions and glass cover are similar to the type MD polyphase.

Type MD—Two-Element Polyphase—This meter has two electromagnets,

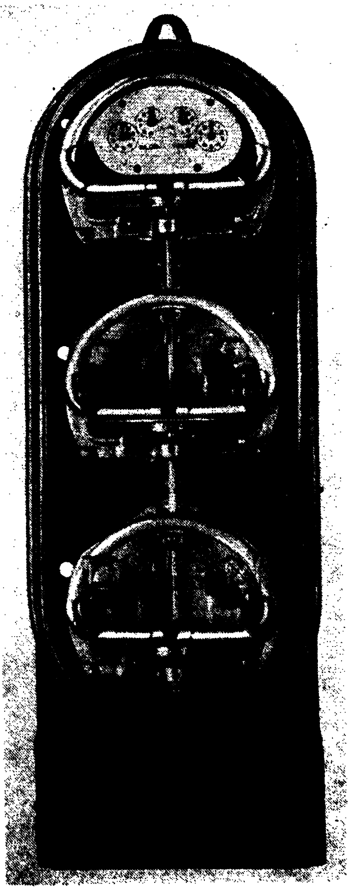


Fig. 13-1. Type MD Three-element Polyphase Meter

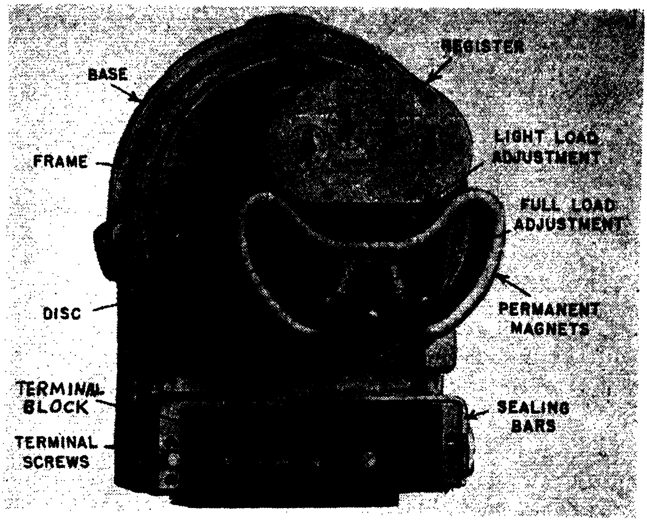


Fig. 13-2. Type MF-A Watthour Meter with Chrome Magnet

each similar to the MD single-phase, which are mounted in vertical tandem on a single shaft. The cast-iron base has a terminal chamber located at the bottom of the meter instead of the two side terminal chambers used previously on M2 polyphase meters. The terminal block has provision for eight large and seven small terminals in accordance with the industry standards existing at time of production.

Type MD—Three-Element Polyphase—This meter is similar in all respects to the type MD two-element poly-

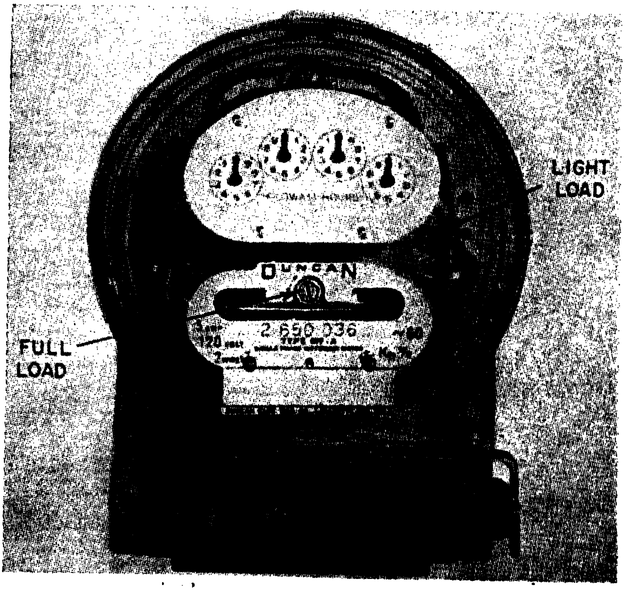


Fig. 13-3. Adjustments of Type MF-A Meter with Alnico Magnet

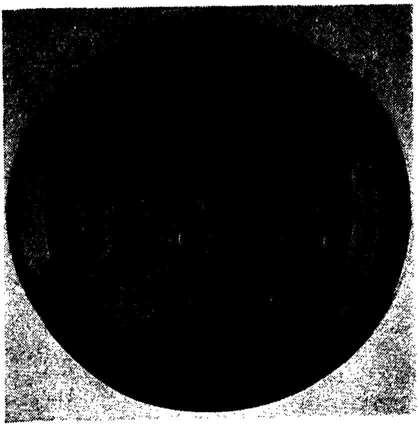


Fig. 13-4. Type MF-S Meter with Alnico Magnet

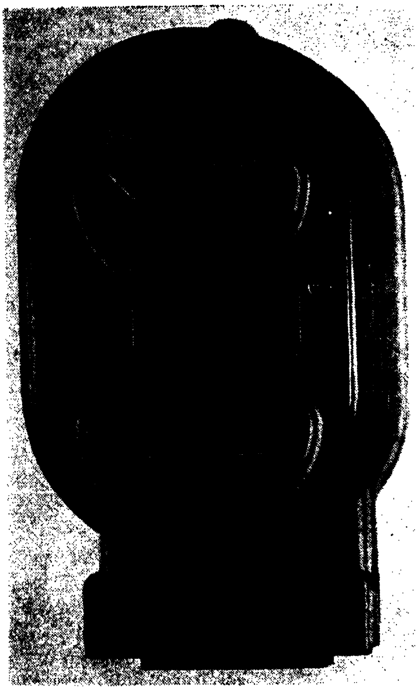


Fig. 13-5. Type MF Two-element, Network Meter

phase meter except for the addition of the third element. See Fig. 13-1.

Type MF Watthour Meters

A complete line of single-phase and polyphase meters identified as type MF was put into production in 1934, incorporating a common design of metering element. This metering element is common to all type MF single-phase and was common to two- and three-element meters of the MF type manufactured until 1936. See Figs. 13-2 to 13-5.

Electromagnet—The MF electromagnetic system consists of a potential and a current electromagnet which are separable and are interchangeable for various ratings.

The current circuit of the meter is designed for high thermal overloads, 400% of rated capacity for the 5- and 15-ampere ratings and 300% for the 50-ampere rating.

An overload compensating plate is riveted to a brass carrying plate and inserted between the poles of the current electromagnet. The MF electromagnet was originally designed for straight-line accuracy to 300% of nominal rating but in 1938, at serial no. 2,600,000, it was changed to extend the overload compensation to 400% of rated load. The 50-ampere meter, however, is limited to 300% of rating by the thermal capacity of the terminals.

The light-load compensating plate is attached to the potential electromagnet and its adjustment is independent of any other adjustment.

The complete electromagnet assembly mounts as a unit in the base. The frame is mounted on the electromagnet and in turn supports the moving element, damping magnets, and register. The frame is cast aluminum and was changed in 1939 to provide for the direct mounting of the Alnico magnet unit.

Permanent Magnet — Alnico (composed of aluminum, nickel, cobalt and iron) has been used for the damping magnet in single-phase type MF meters since 1938, serial no. 2,650,000. See Fig. 13-3. A single, small, horseshoe-shaped Alnico magnet, having a high coercive force, is particularly effective in resisting change due to lightning and other transient surges. Prior to 1938 two chrome magnets were used. See Fig. 13-2. The Alnico damping unit may be adapted to the older type MF meters. Both chrome and Alnico damping units have Class 1 temperature compensation.

By removing two screws, the entire damping unit of either type, including clamp, full load adjustment and temperature compensating clip, can be removed from the meter.

Bearings — The lower bearing was originally of the conventional steel pivot type. The inverted Nobeloy pivot made of non-tarnishable noble metal alloy and the ball bearing type were made available as alternates in 1938. The ball bearing was adopted as standard in 1946. The pivot type bearings used a single synthetic sapphire cup jewel, and two cup jewels of the same design are used for the ball type bearing.

The top bearing consists of a K-monel metal pin which fits into a phosphor bronze sleeve bearing held in the top of the shaft.

Moving Element — The single-phase moving element is an aluminum disk mounted on a shaft. The shaft carries the worm, the removable top bearing sleeve, and the pivot or upper jewel of the lower bearing. The disk has two anti-creep holes and four hundred teeth in the edge for stroboscopic testing, and since 1940 it has also been marked with one hundred division lines.

Register—All of the gear wheels of the register are protected between three parallel plates of rigid construction. The worm wheel assembly is mounted on a separate bracket.

Adjustments—The full-load and light-load adjustments are *microset* and are self-locking.

Full-Load Adjustment—The full-load adjustment is a part of the damping unit and consists of a soft iron plug which is moved in or out by an adjusting screw, thus regulating the flux that cuts the disk. See Figs. 13-2 and 13-3.

Light-Load Adjustment—This adjustment is part of the potential electromagnet assembly, and the operating screw for the light-load adjustment extends through a hole in the frame. See Fig. 13-3.

Inductive-Load Adjustment—The inductive-load adjustment is accomplished by shifting the current coil flux by means of a coil around the poles of the current electromagnet. These coils are connected in series and closed through a resistance. Because of the low resistance drop of the potential coil, a light-load plate of sufficient capacity for providing ample range for that adjustment overlags the potential coil flux, thus requiring shifting of the current coil flux for obtaining the desired quadrature or phasing adjustment.

Register Dial Faces—Aluminum dial faces were adopted as standard for MF meters in 1936, replacing the painted dials used previously. This type of dial was developed primarily to provide a sun-resistant register face for meters installed where they would be subject to direct exposure to the sun. Aluminum dials are available for replacements for type M2, MD and earlier type MF meters.

Types MF-A and MF-S Single-Phase—These are the bottom-connected and socket types, single-phase watthour meters. The MF-A is provided with a die-cast aluminum base, glass cover and a standard single-phase terminal chamber. See Fig. 13-3. Since 1938 porcelain or other inorganic terminal blocks have been supplied in the type MF-A meter. The MF-S is provided with a standard base plate and glass cover for socket mounting. See Fig. 13-4.

Type MF—Two-Element Network—This meter has two electromagnets, each similar to that in the type MF single-phase, which are mounted with two disks in tandem on a single shaft. Except for the addition of a torque-balancing adjustment, the adjustments are the same as for the type MF single-phase meters. Potential indicators are provided. The terminal arrangement and dimensions of the terminal chamber are similar to the MF single-phase. See Fig. 13-5.

Type MF—Two-Element Polyphase—This meter is similar to the type MF

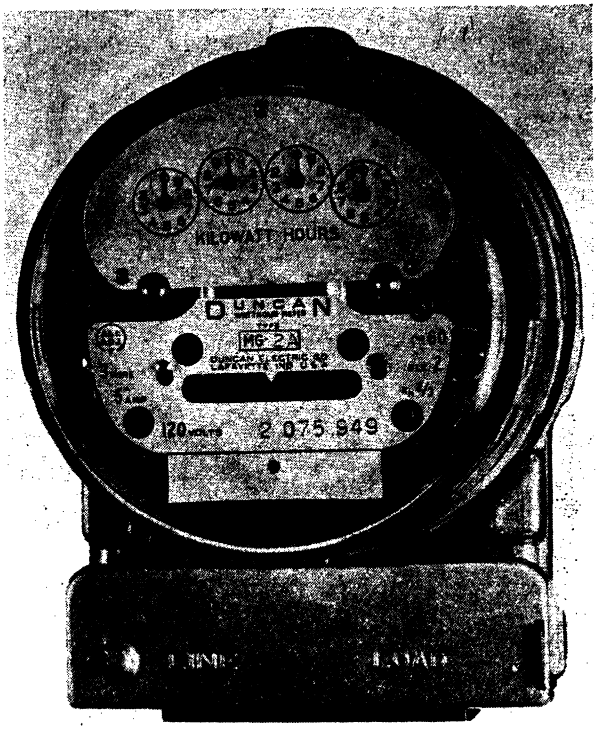


Fig. 13-6. Type MG-2A Two-element Meter

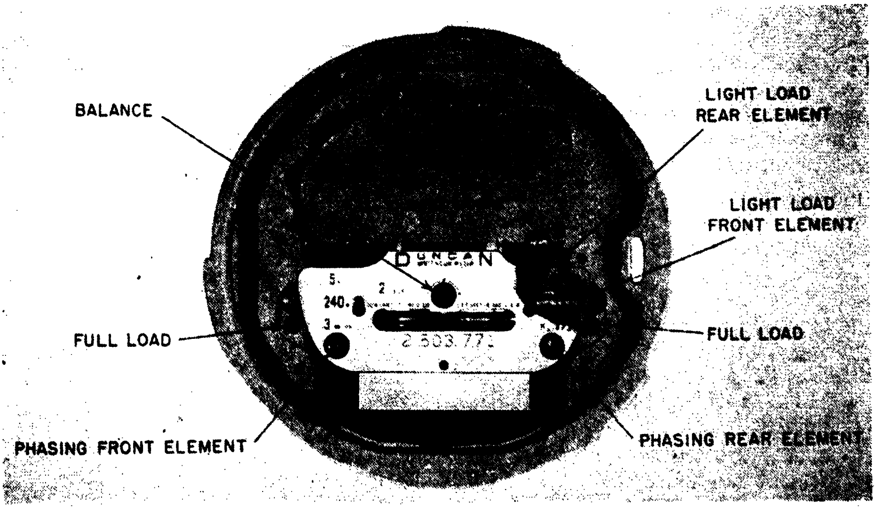


Fig. 13-7. Adjustments on Type MG-2S Polyphase Meter

two-element network, except for the terminal block and chamber which are larger to provide the additional terminals required. Provision is made for demand contact terminal connections. This meter was provided with studless glass covers in 1936.

Type MF—Three-Element Polyphase—This meter is similar to the type MF two-element polyphase meter except for the addition of a third element requiring increased length. It was originally built to use the type MD cover (see Fig. 13-1), but was later modified to use a base 1¾ inches shorter.

Type MG Watthour Meters

The type MG line of two- and three-element meters superseded the two- and three-element type MF line late in 1936. The electromagnets, which are similar to the type MF, operate on a single disk in the two-element types and are mounted in bottom-connected and socket type bases similar to the single-phase type MF.

Damping Magnets—Two Alnico magnets are used which are similar to those now used in type MF and were first introduced with the development of this meter in 1936.

Adjustments—All adjustments are of the Duncan microset type. See Fig. 13-7.

Full-Load Adjustment—The full-load adjustment is a part of the damping magnet unit and consists of a soft iron shunt which is actuated by the full-load adjustment screws.

Light-Load Adjustment—This adjustment is part of the potential electromagnets and is operated by the adjusting screws on the right-hand side of the meter.

Inductive-Load Adjustment — The phasing adjustment on each element consists of a screw-operated rheostat connected to a phasing coil wound on the current electromagnet.

Balance Adjustment—The balancing adjustment originally was operated by two microset screws (Fig. 13-6), but meters above serial no. 2,500,000 have

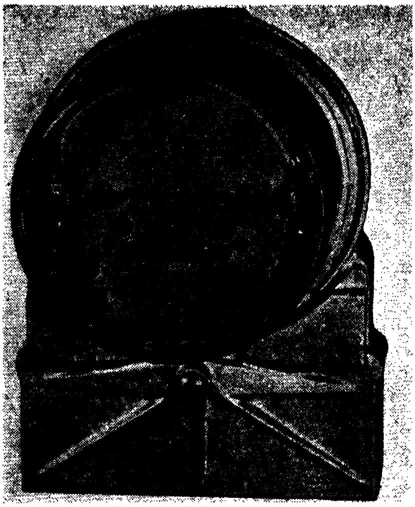


Fig. 13-8. Type MG-2P Meter

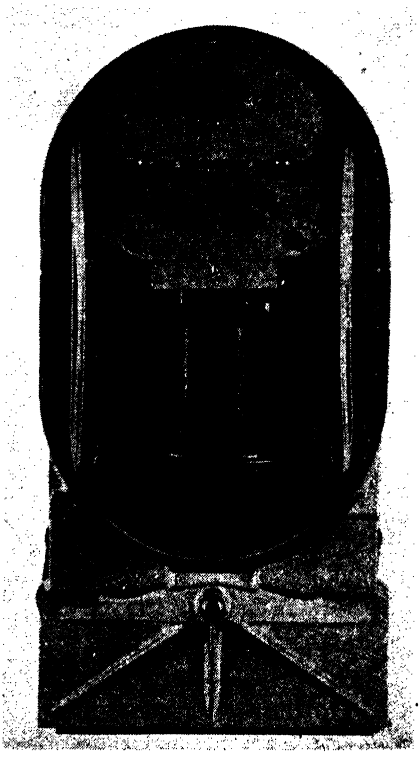


Fig. 13-9. Type MG-3P Meter

balance adjustments which are operated with one screw. See Fig. 13-7.

Type MG-2A and MG-2S Two-Element Network—These are the bottom-connected and socket type two-element network meters. The bases and terminal arrangements are the same as MF-A and MF-S with one additional potential terminal. These meters are for use on three-wire circuits supplied from three-phase, four-wire wye systems but may also be used on any three-wire, single-phase or polyphase circuit.

Types MG-2P and MG-2SP Two-Element Polyphase—These meters are similar to the MG-2A and the MG-2S, except that the meters are provided with standard polyphase terminal arrangements. These meters are for use on three-phase, three-wire circuits; two-phase, three-wire circuits; and two-phase, four-wire circuits. See Fig. 13-8. For two-phase, five-wire circuits, the type MG-2P or MG-2SP meter is supplied with two three-wire elements.

Types MG-2P△ and MG-2S△ Two-Element Delta Polyphase—These meters are of the two-element type, having one two-wire and one three-wire element, for use on three-phase, four-wire, delta circuits used to supply combined light and power.

Types MG-2½P and MG-2½S Two-Element, Four-Wire Polyphase — These meters are of the two-element type, having a split current winding to provide a third current circuit for use on three-phase, four-wire, wye-connected circuits.

Type MG-3P Three-Element Polyphase—These are three-element, two-disk watthour meters for use on three-phase, four-wire, wye circuits. They have three complete elements and are mounted in a case similar in size to that used for the two-element, two-disk MF meter. See Fig. 13-9.

The electromagnets and all other principal parts, including adjustments, are similar to those of the type MG-2 meters.

Type MG-3P△ Three-Element Delta Polyphase—These are three-element, two-disk meters for metering three-phase, four-wire, delta combined light and power circuits.

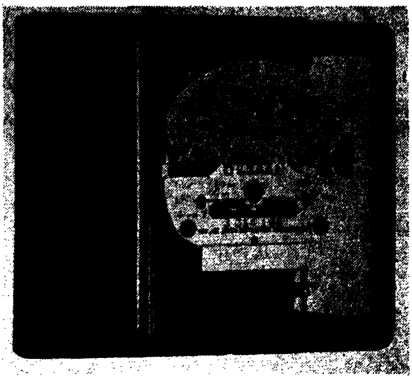


Fig. 13-10. Type MG-2½W Switchboard Meter

Types MG-3P Totalizing—These are three-element meters made both in the self-contained and transformer rated styles. They are special meters used for totalizing a three-phase, three-wire circuit and a two- or three-wire single-phase circuit.

MG Meters for Instrument Transformers—All types of MG meters except the MG-2A and MG-2S two-element network are supplied for use with instrument transformers. The mountings are the same as the corresponding self-contained polyphase types with the addition of the necessary potential terminals. They are designated by a suffix T such as MG-2PT or MG-2½ST, etc.

Switchboard Meters

Switchboard meters are supplied in any rating of the MF or MG line now in production. Superseded types are the M2, MD and the MF polyphase lines.

Types MF-W, MG-2W, MG-2½W and MG-3W Switchboard—These are the present single-phase, two-element, two-and-a-half-element, and three-element meters adapted for switchboard mounting. All parts other than base, cover, terminal and mounting parts are interchangeable with the corresponding service type meter. The cases for the MF-W and MG-2W are the same as the MG-2½W illustrated in Fig. 13-10; the MG-3W is similar except the case is longer to accommodate the third element, and the two disks are arranged in vertical tandem. Switchboard meters are also furnished in cases for semi-flush mounting.

DETAILED DATA AND CONSTANTS TABLES

Tables 13-A to 13-D list detailed data for Duncan watthour meters.

Tables 13-A and 13-B tabulate historical and meter characteristic data.

Tables 13-C and 13-D give constants and register ratio data for d-c and a-c meters.

PORTABLE STANDARD WATTHOUR METERS

Model T-4

This model uses the Type MD meter element. It is provided with 1-, 10-, 20- and 40-ampere coils selected by a rotary switch equipped with a shunting device to prevent the burning of the switch contacts.

A rotary potential switch, giving a series-parallel arrangement of the potential coils, is provided for the 110/220 volt ratings.

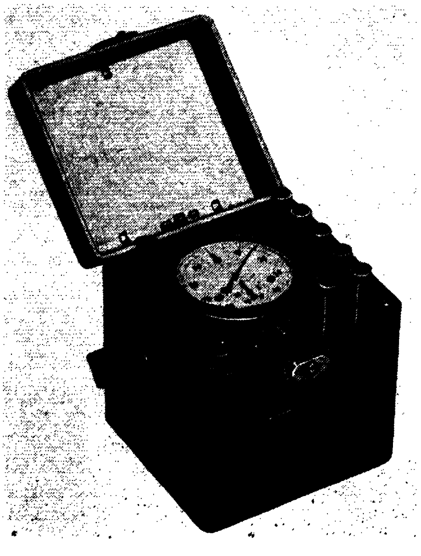


Fig. 13-11. Model TM-1 Portable Test Meter

Model TM

The Model TM line of test meters, using a special MF metering element, in 1938 superseded the Model T-4 which used the MD element. Durability and light weight have been combined by using a cast aluminum alloy for the case, cover, meter frame, and supporting grid.

The shaft and all gears in the register are supported in jewel bearings. There are two sweephands, the smaller one making one revolution for each twenty-five revolutions of the large pointer. Both can be quickly reset to zero.

Separate terminals are used for the different current ratings and a potential toggle switch is provided which allows the meter to be used on either 120- or 240-volt alternating-current circuits. The model TM-1 (Fig. 13-11) has five current ranges—1, 5, 10, 25, and 50 amperes. The TM-2 has three ranges—1, 5, and 15 amperes.

DEMAND METERS

Demand Registers

Duncan mechanical demand registers are of the integrating block-interval type, and can be furnished for any Duncan a-c watthour meter manufactured since 1915, except the studless cover models of MD single-phase and MF two-element meters.

Type T-1 Demand Register — This register was developed in 1932 for the type MD meter. The demand intervals are 15, 30 or 60 minutes. A small self-starting synchronous motor having a speed of 1200 rpm controls the interval.

Operation.. The pusher pointer is advanced by the watthour meter in proportion to the kilowatt demand. The pusher pointer engages a demand scale pointer which it carries along with it over the demand scale. When the demand interval is completed, the pusher pointer returns to the zero position, but the demand indicator remains at that point until a higher demand is recorded. A manual reset

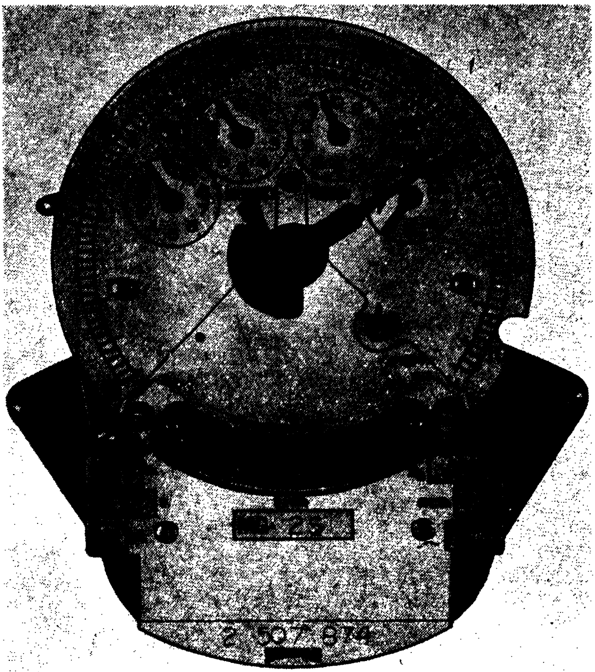


Fig. 13-12. Type T-3 Demand Register

mechanism is provided for resetting the demand pointer to zero.

Type T-2 Demand Register—This type was produced in 1935 and superseded the T-1 demand register.

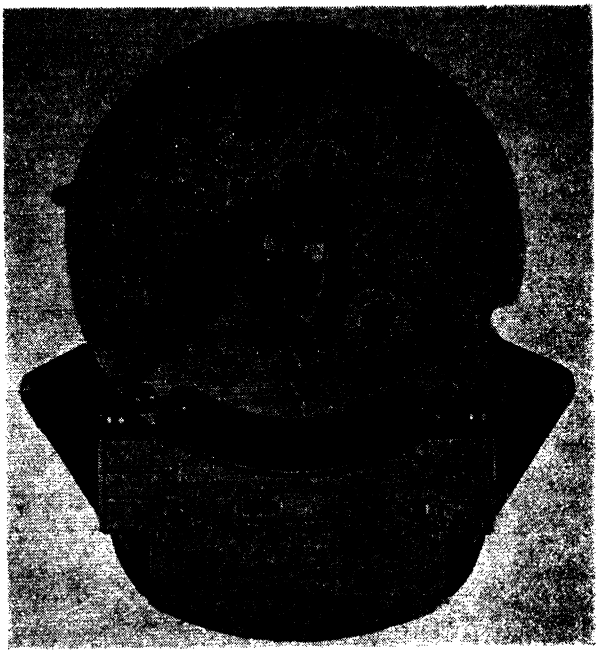
Operation. The principle of operation makes use of a differential, one side of which is normally held in a locked position by a brake while the other side is driven by the watthour meter mechanism. This causes the differential pinion to move, and with it the pusher pointer. At the end of the demand interval, the motor mechanism releases the brake for a few seconds, which permits the pinion of the differential and the driving pointer to return to zero. The brake is then reapplied and the process repeated. There is no load on the motor except for a few seconds at the time of reset, and there is no meshing and unmeshing of gears.

The standard demand register can be changed to a cumulative type by removing the sweephand assembly unit and substituting a cumulative assembly unit.

Type T-3 and T-3C Demand Register—These demand registers (Fig. 13-12) were developed in 1938 and superseded the type T-2. They can be adapted to all Type M2 and MD meters with stud type covers, two-element MF meters with stud covers, all MF single-phase and all MG polyphase meters. The important improvements are the use of a more powerful slow-speed motor, which has a synchronous speed of 240 rpm, and the use of all open spur gears in the timing train, thus eliminating the oil-filled gear box employed in previous registers.

Operation. The principle of operation (similar to the previous type T-2) is as follows: Use is made of a differential, one side of which is normally held in a locked position by a brake while the other side is driven by the watthour meter mechanism. This causes the differential pinion to move and with it the pusher pointer.

Fig. 13-13. Type T-3C Cumulative Demand Register



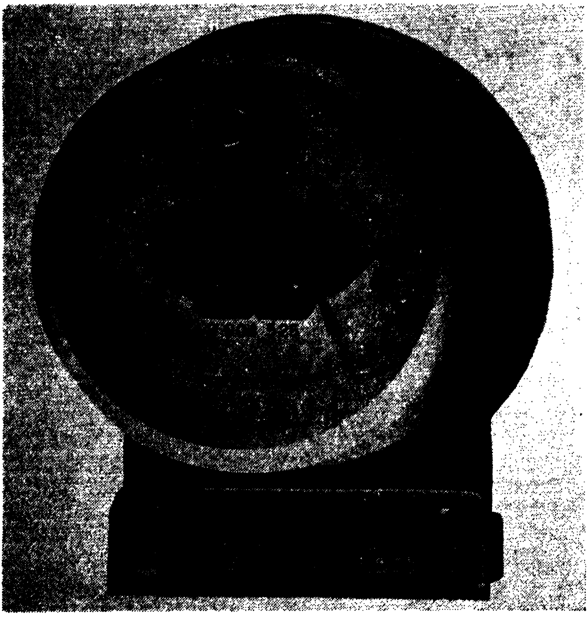


Fig. 13-14. Type TF-A Combination Watthour and Thermal Watt Demand Meter

At the end of the demand interval, the motor mechanism releases the brake for a few seconds, which permits the pinion of the differential and the driving pointer to return to zero. The brake is then reapplied and the process repeated. There is no load on the motor except for a few seconds at the time of reset, and there is no meshing and unmeshing of gears.

The T-3C cumulative demand register (Fig. 13-13) is exactly like the T-3 construction except that the standard sweephand assembly is replaced by a cumulative assembly unit containing the cumulator gearing and dials. This arrangement enables either type to be converted to the other.

Duncan Thermal Demand Meters

This line of thermal watt demand meters was put into production by Duncan, starting with single-phase types in 1946 and followed by polyphase in 1947. The single-phase meters are furnished as separate demand meters, type T; or in combination with a watthour meter, Type TF, the watthour meter element being of the MF design. Both types T and TF (Fig. 13-14) are supplied in mountings for either socket or bottom connection and designated by the suffix S or A. The polyphase types of thermal demand meters are not furnished in combination with watthour meters but only as separate demand meters. The nominal current and voltage ratings correspond to the standard ratings of watthour meters. The self-contained types are furnished in 15 and 50 amperes and the instrument transformer types in 2½ and 5 amperes. The scales of the various ratings are as given in *EEI-AEIC Specification MS-5,* shown in Section 4.

The Thermal Watt Demand Element—The main feature of the thermal demand element design is simplicity. A rugged high-torque bi-metallic actuating element of the same design is employed in all types. In the single-phase types (Fig. 13-15) a separate transformer is mounted on the side of

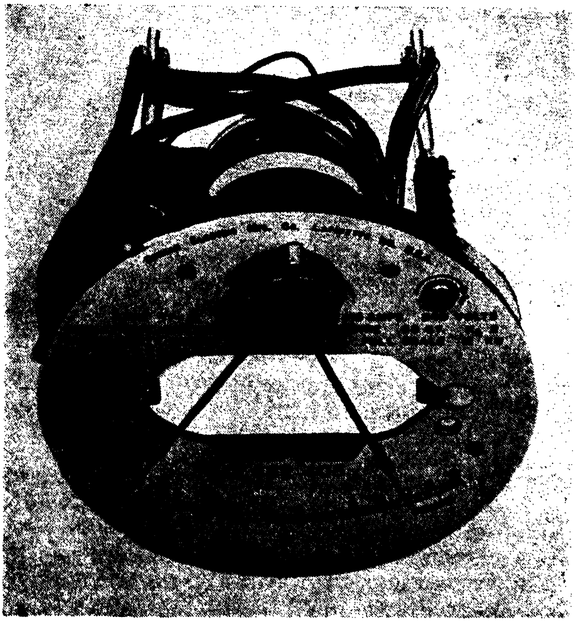


Fig. 13-15. Thermal Watt Demand Element Typical of all Types

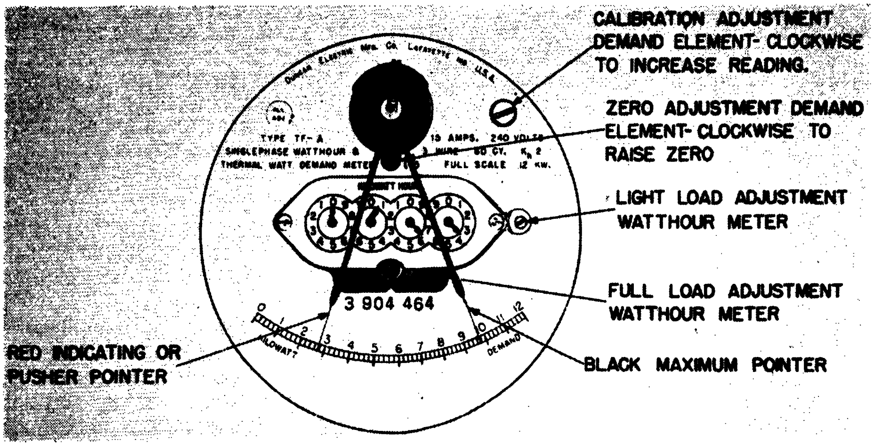

CALIBRATION ADJUSTMENT DEMAND ELEMENT- CLOCKWISE TO INCREASE READING.
ZERO ADJUSTMENT DEMAND ELEMENT- CLOCKWISE TO RAISE ZERO
LIGHT LOAD ADJUSTMENT WATTHOUR METER
FULL LOAD ADJUSTMENT WATTHOUR METER
BLACK MAXIMUM POINTER
RED INDICATING OR PUSHER POINTER
Duncan Electric Mfg. Co. Lafayette Ind. U.S.A.
TYPE TF-A
SINGLEPHASE WATTHOUR &
THERMAL WATT DEMAND METER
15 AMPS. 240 VOLTS
3 WIRE 60 CY. Kh 2
FULL SCALE 12 KW.
3 904 464
0 1 2 3 4 5 6 7 8 9 10 11 12
KILOWATT DEMAND

Fig. 13-16. Adjustments on Type TF Meters

the element making the unit readily demountable from the meter base in either the combination or separate meter. The polyphase types employ an identical element but with the necessary two or three transformers mounted in the base and the leads rearranged accordingly.

A unique method of retaining the maximum pointer on the scale effectively holds the pointer in its position, while at the same time permitting it to be moved by the pusher pointer with a minimum of driving force. This is accomplished by an especially packed chamber containing silicone grease which has practically constant viscosity from −50 F to +400 F.

The adjustments of the thermal demand meter are shown in Fig. 13-16. As in all Duncan meters, these are accessible from the front and can be operated with standard screw drivers and function in a uniform direction. The calibrating adjustment is made by turning the adjustment screw in the upper right portion of the dial after a uniform test load of 60% to 90% of full scale has been applied to the meter for a minimum of three times the rated demand interval. The zero adjustment may be made when necessary by turning the adjustment screw directly below the pointer shaft after the meter has had potential applied for a minimum of thirty minutes.

A positive type of pointer reset is employed. The movement is limited to avoid damage to pointers or element and is arranged so that it can be sealed only in the right position.

Types TF-A and TF-S Single-Phase Watthour and Thermal Watt Demand—These are the bottom-connected and socket type combination single-phase watthour and thermal watt demand meters employing the MF watthour meter element and the T thermal element. The detachable thermal unit is interchangeable between the TF-A and TF-S. The service connections are identical to the corresponding watthour meters.

Types T-A and T-S Single-Phase Thermal Watt Demand—These are the bottom-connected and socket types of thermal demand meters employing the T thermal element. The terminal arrangement and general dimensions are similar to the corresponding single-phase combination type. These two types use standard thermal units but the leads are arranged for their respective bases and are not interchangeable.

Types T-2A and T-2S Network Thermal Watt Demand—These are the bottom-connected and socket types of two-element network demand meters. The bases and terminal arrangements are the same as the single-phase types

T-A and T-S with one additional potential terminal. These meters are for use on three-wire circuits supplied from three-phase, four-wire systems but may also be used on any three-wire, single-phase or polyphase circuit.

Types T-2P and T-2SP Two-Element Polyphase Thermal Watt Demand—These are the bottom-connected and socket types of two-element polyphase thermal demand meters. The covers are similar to the corresponding combination single-phase type; the bases are similar except the standard polyphase watthour meter terminals are provided.

Types T-2P△ and T-2S△ Two-Element Delta Polyphase Thermal Watt Demand—These are the bottom-connected and socket types, having one two-wire and one three-wire element for use on three-phase, four-wire delta circuits used to supply combined light and power. The mountings are the same as the corresponding types T-2P and T-2SP with the addition of the necessary current terminals.

Types T-2½P and T-2½S Two-Element Four-Wire Polyphase Thermal Watt Demand—These are the bottom-connected and socket types of two-element demand meters having a split current winding to provide a third current circuit for use on three-phase, four-wire circuits. The mountings are the same as the corresponding Types T-2P and T-2SP with the addition of the necessary current terminals.

Thermal Demand Meters for Instrument Transformers—All types of thermal demand meters are supplied for use with instrument transformers. The mountings are the same as for the corresponding types of self-contained meters with the addition of the necessary potential terminals. These meters are designated by a suffix T as types TF-AT, T-ST, T-2PT, etc.

TABLE 13-A
METER DATA
DUNCAN DIRECT-CURRENT WATTHOUR METERS

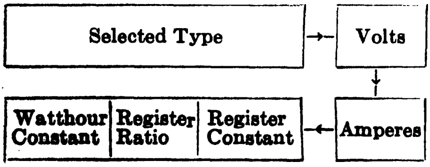
Type	First Mfd (Year)	Data Applies to Meter Size		Full Load Torque (Mmg)	Weight of Moving Element (Grams)	Ratio of Torque to Weight	Coil Loss	
		(Amps)	(Volts)				Potential (Watts)	Current (Watts)
A	1902	5	110	180	180	1	5	1.3
E	1909	5	110	140	107	1.3	4.4	1.2
F	1909	300	220	300	200	1.5	4.4	1.2
R	1911	50	110	215	203	1.1	7.7	1.2
EA	1912	25	110	170	175	0.97	5.2	1.2
ER	1912	100	110	180	105	1.7	7.7	1.2
FR	1912	100	110	180	105	1.7	7.7	1.2
EK	1922	10	110	155	114	1.36	5	1.2

TABLE 13-B
METER DATA
DUNCAN ALTERNATING-CURRENT WATTHOUR METERS

Type	First Mfd (Year)	Data Applies to Meter Size			Full Load Torque (Mmg)	Weight of Moving Element (Grams)	Ratio of Torque to Weight	Coil Loss		Temp. Coefficient	
		(Amps)	(Volts)	(Cycles)				Potential (Watts)	Current (Watts)	Unity PF (%/°F)	0.5 PF Lagging (%/°F)
M	1912	5	110	60	115	46	2.5	1.25	0.6	+0.03	−0.035
M1	1913	5	110	60	60	28	2.1	1.1	0.6	+0.03	−0.035
M2	1915	5	110	60	40	11	3.63	1.1	0.3	+0.03	−0.035
M2P	1915	5	110	60	75	21	3.5	1.1	0.3	+0.03	−0.035
MD	1926	5	115	60	38	15.2	2.5	1.3	0.2	+0.025	−0.032
MD-2 El.	1927	5	115	60	80	36	2.2	1.3	0.2	+0.025	−0.032
MF	1934	5	115	60	46	15	3.0	0.9	0.25	Zero	−0.0306
MF-2 El.	1934	5	115	60	92	36	2.55	0.9	0.25	Zero	−0.0306
MG-2	1936	5	120	60	56.4	20.2	2.79	1.34	0.294	+0.011	−0.011

DIRECTIONS FOR USE OF TABLES

Constants and register ratio data for Duncan d-c and a-c meters may be obtained from Tables 13-C and 13-D as illustrated in the following key:



Key for Constants Tables

Select the type of meter in question from the list in the upper left-hand corner of the table.

Next, select the voltage on the same line; then in the same column as the voltage, read down until the desired current rating of the meter is reached.

The constants and register data then will be found on the same line to the left of the ampere size.

TABLE 13-C

CONSTANTS AND REGISTER RATIO DATA

FOR DUNCAN D-C WATTHOUR METERS

Model			VOLTAGE													
A		2-Wire			110					220				550		
		3-Wire								220						
D		2-Wire	110					220					550			
		3-Wire						220					550			
E, C, F, R, EA, ER & FR		2-Wire		110					220						550	
(Serial Nos. 76,000–150,000)		3-Wire							220							
E, C, F, R, EA, ER & FR		2-Wire					110					220				550
(Serial Nos. above 150,000)		3-Wire										220				
EK		2-Wire				110					220					
		3-Wire									220					
Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	AMPERE RATING													
1/8			2½													
1/8	800	1		2½			2½									
1/4			5					2½								
1/4	40	1			2½											
1/4	40	1			5											
1/4	400	1		5		5	5		2½			2½				
3/8	266 2/3	1					7½									
1/2			7½													
1/2			10					5					2½			
1/2	20	1			7½					2½						
1/2	20	1			10					5						
1/2	200	1		7½											2½	
1/2	200	1		10		10	10		5		5	5				
5/8	160	1														2½
3/4	133 1/3	1				15	15					7½				
1			15					7½								
1			25					10					5			
1	10	1			15					7½				2½		
1	10	1			25					10				5		
1	100	1		15					7½							
1	100	1		25					10		10	10			5	
1 1/4	80	1				25										5
1 1/4	800	10					25									
1 1/2	66 2/3	1									15	15				
1 7/8	53 1/3	1														7½
2								15					7½			
2			50					25					10			
2	5	1								15				7½		
2	5	1			50					25				10		
2	50	1							15						7½	
2	50	1		50					25						10	
2 1/2	40	1									25					10
2 1/2	400	10					50					25				
3			75													
3	3 1/3	1			75											
3	33 1/3	1		75												
3 3/4	266 2/3	10					75									15
4			100					50								
4	25	1		100					50							
4	25	10			100					50						
5													15			
5													25			
5	20	1													15	
5	20	1													25	
5	20	10												15		
5	20	10												25		
5	200	10					100					50				
6			150					75								
6	16 2/3	1		150					75							
6	16 2/3	10			150					75						
6 1/4	160	10														25
7 1/2	133 1/3	10					150					75				
8			200					100								
8	12 1/2	1		200					100							
8	12 1/2	10			200					100						
10													50			
10	10	10												50		
10	100	10					200					100			50	
12			300					150								
12	8 1/3	1		300					150							
12	8 1/3	10			300					150						
12 1/2	80	10														50
15	66 2/3	10					300					150				
16								200					75			
16	6 1/4	1							200							
16	6 1/4	10								200				75		

TABLE 13-C (Continued)—DUNCAN Constants and Register Ratio Data

Model			VOLTAGE													
A		2-Wire			110					220				550		
		3-Wire								220						
D		2-Wire	110					220					550			
		3-Wire						220					550			
E, C, F, R, EA, ER & FR (Serial Nos. 76,000–150,000)		2-Wire		110					220						550	
		3-Wire							220							
E, C, F, R, EA, ER & FR (Serial Nos. above 150,000)		2-Wire					110					220				550
		3-Wire										220				
EK		2-Wire				110					220					
		3-Wire									220					
Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	AMPERE RATING													
16	62 1/2	10													75	
18 3/4	53 1/3	10														75
20			400										100			
20	5	10			450									100		
20	50	10		450			400					200			100	
22 1/2	44 4/9	10					450									
25			500													
25			600					300								
25	4	1		600					300							
25	4	10			600					300						
25	40	10					500									100
30													150			
30	3 1/3	10			800									150		
30	33 1/3	10					600					300			150	
37 1/2	266 2/3	100														150
40			800					400								
40			1000										200			
40	25	10		800												
40	25	10		1000			800		450			400			200	
40	25	100			1000					450				200		
45	22 2/9	10										450				
50								500								
50			1200					600								
50	20	10		1200			1000		600							
50	20	100								600						
50	200	100										500				200
60			1500										300			
60	16 2/3	10		1500											300	
60	16 2/3	100								800				300		
60	166 2/3	100					1200					600				
75	133 1/3	100					1500									300
80								800								
80	12 1/2	10							800							
80	12 1/2	100								1000				450		
80	125	100										800				
100			2000					1000					400			
100	100	100		2000			2000		1000			1000			450	400
100	10	100												600		
112 1/2	88 8/9	100														450
120													500			
120								1200					600			
120	8 1/3	10							1200							
120	83 1/3	10													600	
120	83 1/3	100										1200				
125	80	100														500
150	66 2/3	100										1500				600
160								1500					800			
160	6 1/4	10							1500							
160	6 1/4	100												800		
160	62 1/2	10													800	
200								2000					1000			
200	5	100												1000		
200	50	100							2000			2000			1000	800
250													1200			
250	40	10													1200	
250	40	100														1000
300													1500			
300	33 1/3	10													1500	
300	33 1/3	100														1200
375	266 2/3	1000														1500
400													2000			
400	25	100													2000	
500	200	1000														2000

R_g (Gear Ratio) = R_r (Register Ratio) × 100

TABLE 13-D

CONSTANTS AND REGISTER RATIO DATA

FOR DUNCAN A-C WATTHOUR METERS

Type				VOLTAGE																			
M	Single-Phase, 2-Wire, 60 to 133 Cycle			110			220																
	Single-Phase, 3-Wire, 60 to 133 Cycle						220																
M1	Single-Phase, 2-Wire, 25 to 133 Cycle				110			220						550									
	Single-Phase, 3-Wire, 25 to 133 Cycle							220															
M1, M2	Single-Phase, 2-Wire, 25 to 133 Cycle				110				220			440	550										
&	Single-Phase, 3-Wire, 25 to 133 Cycle								220														
M2P	Polyphase, 25 to 133 Cycle								110			220						440	550				
MD	Single-Phase, 25 to 133 Cycle					115				230					460	575							
	*Two-Element, 25 to 133 Cycle									115					230					460	575		
	Three-Element, 25 to 133 Cycle										115						230					460	575
MP	Single-Phase, 25 to 60 Cycle					120				240					480								
&	*Two-Element, 25 to 60 Cycle									120					240					480			
MG	Three-Element, 25 to 60 Cycle										120						240					480	
Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	Gear Ratio (R_g)	AMPERE RATING Four Dial Registers																			
1/8	800	1	80000		2½																		
1/6	800	1	60000			2½																	
1/4	400	1	40000	5	5			2½															
1/3	400	1	30000			5				2½													
3/8	266 2/3	1	26666 2/3		7½																		
1/2	266 2/3	1	20000								2½												
1/2	200	1	20000	10	10		5	5	5														
5/8	160	1	16000											2½									
2/3	200	1	15000			10				5					2½								
3/4	133 1/3	1	13333 1/3	15	15			7½															
1	133 1/3	1	10000			15					5						2½						
1	100	1	10000	20			10	10	10			5											
1 1/4	800	10	80000	25																			
1 1/4	80	1	8000		25								5	5									
1 1/3	100	1	7500							10					5					2½			
1 1/2	66 2/3	1	6666 2/3				15	15	15														
1 2/3	80	1	6000			25										5							
1 7/8	53 1/3	1	5333 1/3											7½									
2	66 2/3	1	5000							15	10						5					2½	
2	50	1	5000				20					10						5					
2 1/2	400	10	40000	50			25																
2 1/2	40	1	4000		50			25	25				10	10					5				
2 2/3	50	1	3750												10					5			
3	44 4/9	1	3333 1/3								15												
3	33 1/3	1	3333 1/3									15											
3 1/3	40	1	3000			50				25						10					5		
3 3/4	266 2/3	10	26666 2/3	75																			
3 3/4	26 2/3	1	2666 2/3		75								15	15									
4	333 1/3	10	25000												15		10					5	
4	25	1	2500															10					
5	266 2/3	10	20000			75					25					15							5
5	200	10	20000	100			50																
5	20	1	2000		100			50	50			25							10				
5 1/3	250	10	18750																	10			
6	222 2/9	10	16666 2/3														15						
6	166 2/3	10	16666 2/3															15					
6 1/4	160	10	16000										25										
6 1/4	16	1	1600											25									
6 2/3	200	10	15000			100				50					25						10		
7 1/2	133 1/3	10	13333 1/3	150	150		75		75										15				
7 1/2	13 1/3	1	1333 1/3					75															
8	166 2/3	10	12500																	15		10	
8 1/3	160	10	12000													25							
10	133 1/3	10	10000			150				75	50						25				15		10
10	100	10	10000	200	200		100	100	100			50						25					
12	111 1/9	10	8333 1/3																			15	
12 1/2	80	10	8000										50	50					25				
13 1/3	100	10	7500			200				100					50					25			
15	88 8/9	10	6666 2/3								75												15
15	66 2/3	10	6666 2/3	300	300		150	150	150			75											
16 2/3	80	10	6000													50					25		
18 3/4	53 1/3	10	5333 1/3										75	75									
20	66 2/3	10	5000			300				150	100				75		50					25	
20	50	10	5000	400	400		200	200	200			100						50					
22 1/2	44 4/9	10	4444 4/9		450																		
25	53 1/3	10	4000													75							25
25	40	10	4000	500	500								100	100					50				
26 2/3	50	10	3750			400				200					100					50			
30	44 4/9	10	3333 1/3								150						75						
30	33 1/3	10	3333 1/3		600		300	300	300			150						75					
33 1/3	40	10	3000													100					50		
37 1/2	26 2/3	10	2666 2/3										150	150					75				
40	333 1/3	100	25000							300	200				150		100			75		50	

TABLE 13-D (Continued)—DUNCAN Constants and Register Ratio Data

Type				VOLTAGE																			
M	Single-Phase, 2-Wire, 60 to 133 Cycle			110			220																
	Single-Phase, 3-Wire, 60 to 133 Cycle						220																
M1	Single-Phase, 2-Wire, 25 to 133 Cycle				110			220						550									
	Single-Phase, 3-Wire, 25 to 133 Cycle							220															
M1, M2	Single-Phase, 2-Wire, 25 to 133 Cycle				110				220			440	550										
&	Single-Phase, 3-Wire, 25 to 133 Cycle								220														
M2P	Polyphase, 25 to 133 Cycle								110			220						440	550				
MD	Single-Phase, 25 to 133 Cycle					115				230					460	575							
	*Two-Element, 25 to 133 Cycle									115					230					460	575		
	Three-Element, 25 to 133 Cycle										115						230					460	575
MF	Single-Phase, 25 to 60 Cycle					120				240					480								
&	*Two-Element, 25 to 60 Cycle									120					240					480			
MG	Three-Element, 25 to 60 Cycle										120						240					480	
Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	Gear Ratio (R_g)	AMPERE RATING Four Dial Registers																			
40	25	10	2500		800		400	400	400			200						100					
45	22 2/9	10	2222 2/9					450															
50	266 2/3	100	20000													150					75		50
50	200	100	20000				500																
50	20	10	2000		1000			500					200	200					100				
53 1/3	250	100	18750							400					200					100			
60	22 2/9	10	1666 2/3								300						150					75	
60	166 2/3	100	16666 2/3									300						150					
60	16 2/3	10	1666 2/3		1200			600															
66 2/3	200	100	15000													200					100		
75	177 7/9	100	13333 1/3																				75
75	133 1/3	100	13333 1/3										300						150				
75	13 1/3	10	1333 1/3		1500									300									
80	166 2/3	100	12500								400				300		200			150		100	
80	125	100	12500					800				400						200					
100	133 1/3	100	10000													300					150		100
100	100	100	10000		2000			1000					400	400					200				
106 2/3	125	100	9375												400					200			
112 1/2	88 8/9	100	8888 8/9											450									
120	111 1/9	100	8333 1/3														300					150	
120	83 1/3	100	8333 1/3					1200										300					
125	80	100	8000											500									
133 1/3	100	100	7500													400					200		
150	88 8/9	100	6666 2/3																				150
150	66 2/3	100	6666 2/3					1500						600					300				
160	83 1/3	100	6250														400			300		200	
160	62 1/2	100	6250															400					
200	66 2/3	100	5000																		300		200
200	50	100	5000					2000						800					400				
213 1/3	62 1/2	100	4687 1/2																	400			
240	55 5/9	100	4167 2/3																			300	
250	40	100	4000											1000									
266 2/3	50	100	3750																		400		
300	44 4/9	100	3333 1/3																				300
300	33 1/3	100	3333 1/3											1200									
320	41 2/3	100	3125																			400	
375	26 2/3	100	2666 2/3											1500									
400	33 1/3	100	2500																				400
500	20	100	2000											2000									
				Five Dial Registers																			
8	16 2/3	1	1250																	15		10	
10	13 1/3	1	1000								50						25						
12	11 1/9	1	833 1/3																			15	
13 1/3	10	1	750												50					25			
20	6 2/3	1	500														50					25	
26 2/3	5	1	375																	50			
40	3 1/3	1	250																			50	

Higher Current and Voltage Ratings Proportional

This table may include ampere sizes which were not produced in certain types of meters due to the fact that all meter types in each group or column were not always made in the same current ratings. However, all ampere ratings of all meters in the group have been listed.

For type MF and MG instrument transformer meters, having 2½ ampere current coils, use data for meter having one-half the required current rating. *See Section 17 for Standard Dial Constants.*

*** For two-elements, three-phase, four-wire (2½ element) meters, the watthour constant (K_h) is double that of the standard two-element of the corresponding rating; and the register ratio (R_r) is one-half. The two-element three-phase, four-wire, delta meters have the same watthour constant and register ratio as the standard two-element of corresponding rating.**

SECTION 14

GENERAL ELECTRIC COMPANY METERS

The following descriptive material pertains to types of meters placed in production since 1924 by the General Electric Company. Information on other direct- and alternating-current types may be found in the appendix and previous editions of the *Electrical Metermen's Handbook*. Detailed data and constants, however, are included for all types.

Only salient features and major changes in meters are described. More detailed information concerning the meter types may be obtained from the manufacturer's published material.

ALTERNATING-CURRENT WATTHOUR METERS

Single-Phase Meters

Type I-15—One Element

This meter was designed to provide a 25-cycle meter having improved performance characteristics over preceding 25-cycle types.

Type I-16—One Element

This meter was radically changed from the preceding types. The full load disk speed was reduced one-half with a corresponding increase in the watthour constants. The load range was extended to 300% of rated current. Temperature compensation for Class I errors was provided. A new style of glass cover was used which was secured to the meter base with a bayonet joint eliminating the need for cover studs. The cover may be sealed separate from the terminal chamber or both may be under one seal.

Type I-20—One Element

This meter has the same general characteristics as the Type I-16 but differs in mechanical design. This type has had a number of forms indicated by sub type letters A, B and C.

The Type I-20-A provided a die-cast aluminum base, and improved glass cover and sealing arrangement.

The Type I-20-B provided a new terminal block design that allows the meter to be removed without disconnecting the line and load leads.

The Type I-20-C included a die-cast aluminum protective enclosure with test facilities.

This meter is now standard for 25 cycles only.

Type I-20-S—One Element

This meter is radically different from preceding types in the method of making line and load connections which is by means of switch blade terminals that engage into connecting clips on the meter socket or mounting arrangement. The meter element is the same as the Type I-20. With this type of meter and mounting arrangement, as with the corresponding A type, only one seal is required to protect the meter and its connections to line and load wires.

Type I-30-A—One Element

This meter is similar in appearance to the Type I-20 but has an electromagnet of new design which further extends the load range, improves the general performance characteristics and includes temperature compensation for both Class I and Class II errors. The permanent magnets were originally of the conventional chrome-steel type. They were later changed to Alnico which greatly reduced their susceptibility to lightning and surge currents. See Fig. 14-1.

Type I-30-S—One Element

This meter is similar to the Type I-30-A except that it is of the detachable or socket type. See Fig. 14-2.

Type I-50-A—One Element

This meter is of a completely new design. See Fig. 14-3. Standard di-

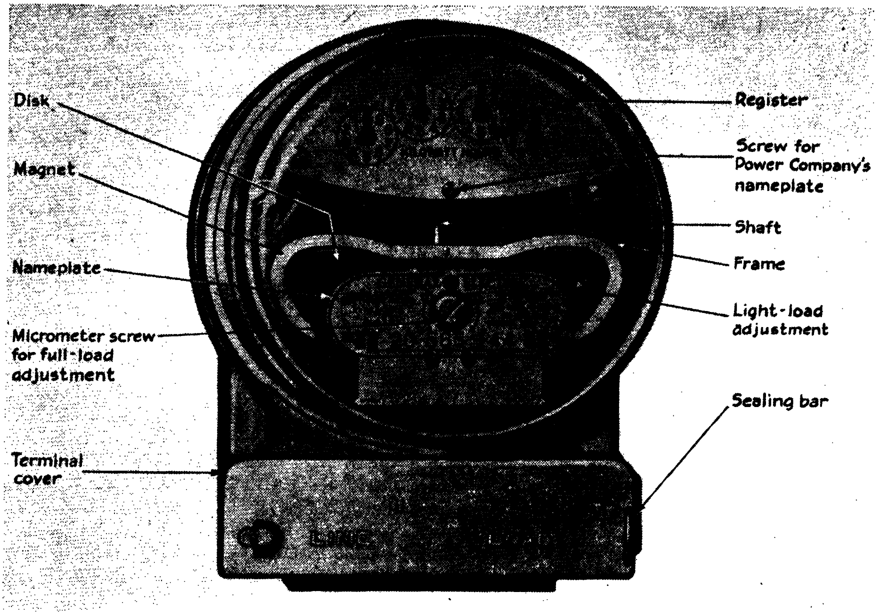


Fig. 14-1. Type I-30-A Single-phase Watthour Meter

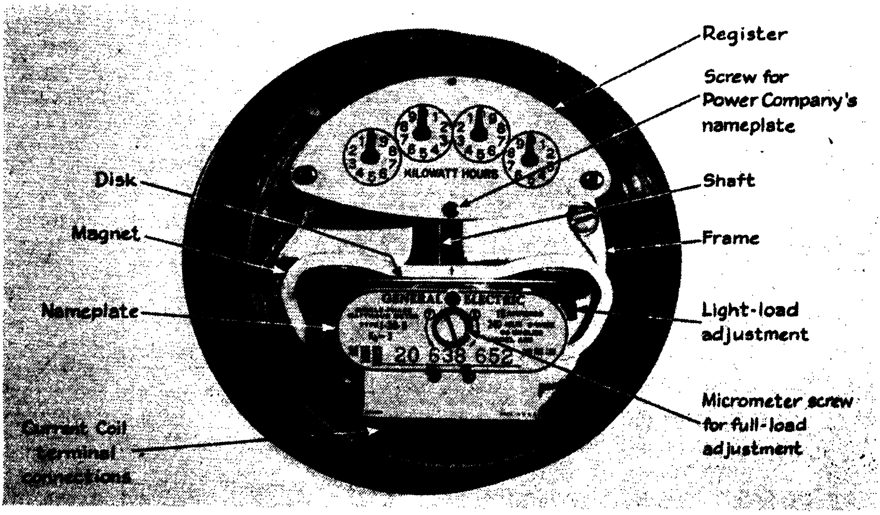

Register
Screw for Power Company's nameplate
Shaft
Frame
Light-load adjustment
Micrometer screw for full-load adjustment
Disk
Magnet
Nameplate
Current Coil terminal connections
KILOWATT HOURS
GENERAL ELECTRIC
20 638 652

Fig. 14-2. Type I-30-S Single-phase Watthour Meter

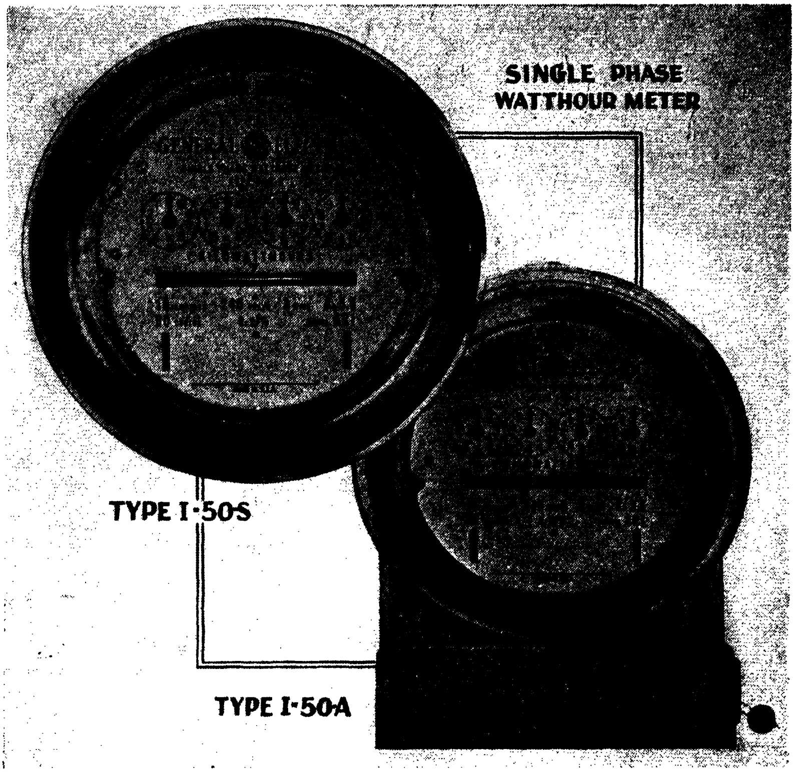


Fig. 14-3. Types I-50-A and I-50-S Single-phase Watthour Meters

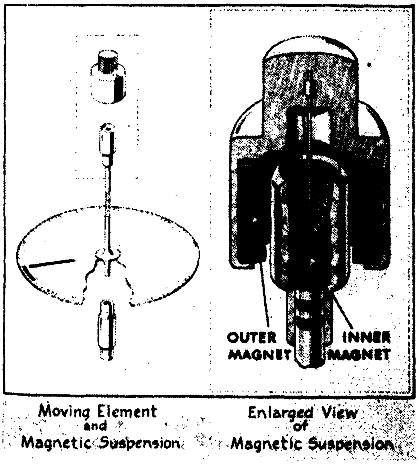

OUTER MAGNET
INNER MAGNET
Moving Element and Magnetic Suspension
Enlarged View of Magnetic Suspension

Fig. 14-4. Moving Element and Magnetic Suspension of 1-50 Single-phase Watthour Meter

mensions of base and terminal chamber are retained. Connections to the meter are made directly to the current coil terminals. All joints and contacts in the series circuit are eliminated. Terminal block is of Nocar, a new, non-carbonizing, arc-resisting compound.

Magnetic suspension of the moving system displaces the conventional jewel-type bearing in earlier meters. See Fig. 14-4. Unit construction features this design. The potential and current coils are molded securely in place on the iron core with insulating materials. The damping magnets are die cast as inserts in the aluminum alloy frame, materially reducing side thrust of the moving system. Coordinated insulation and a relief gap provide a controlled breakdown point.

Calibrating adjustments for full and light load are of the micrometer type.

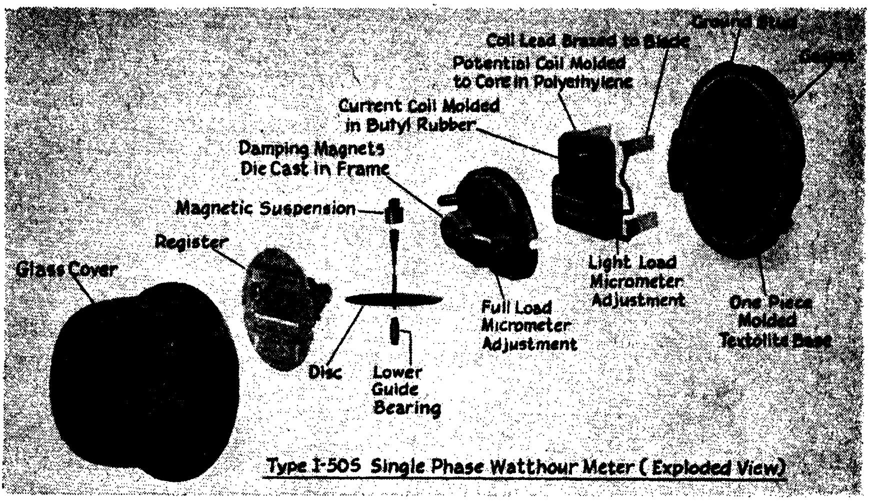

Ground Stud
Coil Lead Brazed to Blade
Gasket
Potential Coil Molded to Core in Polyethylene
Current Coil Molded in Butyl Rubber
Damping Magnets Die Cast in Frame
Magnetic Suspension
Register
Glass Cover
Light Load Micrometer Adjustment
Full Load Micrometer Adjustment
One Piece Molded Textolite Base
Disc
Lower Guide Bearing
Type I-50S Single Phase Watthour Meter (Exploded View)

Fig. 14-5. Exploded View of I-50-S Single-phase Watthour Meter

Inductive load compensation is a permanent factory adjustment. The meter has improved overload characteristics and thermal rating. Full-load speed is 16 2/3 rpm. The weight is reduced 30 per cent.

Type I-50-S—One Element

This meter is similar to the I-50-A except that it is of the detachable or socket type. See Fig. 14-3. The current coil leads are brazed to the terminal blades, eliminating screw-type joints. The base is a one-piece, molded textolite part, incorporating a new type of cover gasket. Fig. 14-5 shows an exploded view. The meter retains the same standardized mounting dimensions as the I-30-S.

Two-Element Three-Wire Meters

Type I-18—Two Element

This meter was designed for use on three-wire circuits of a three-phase, four-wire system where the circuit consists of two phase wires and neutral, or on three-wire, single-phase circuits. The meter elements were similar to those used in the Type I-16 single-phase meter.

The cover is secured to the base by means of a locking lever which engages studs on either side of the base.

This meter is now standard for 25 cycles only.

Type V-2-A—Two Element

In this meter both elements operate upon a single disk. The terminal dimensions are the same as in the Type I-30 single-phase meter. See Fig. 14-6.

Type V-2-S—Two Element

This meter is similar to the Type V-2-A except that it is of the detachable or socket type.

Polyphase Meters

Type D-8—Two Element

This meter is designed for 25-cycle circuits and employs the element used in the Type I-15 single-phase meter.

Types D-9 and D-13—Three Element

The Type D-9 is similar to the Type D-7, introduced prior to 1924, except for the addition of the third element. The Type D-13 is a three-element, 25-cycle meter and employs the element used in the I-15 meter.

Type D-14—Two Element

This meter has elements similar to the Type I-16 but with temperature compensation for both Class I and Class II errors. The D-14 meter is now standard for 25 cycles only.

Type D-15—Three Element

This meter is similar to the Type D-14 except for the addition of one more complete element. The D-15 meter is now standard for 25 cycles only.

Type V-series—Two Element

These meters are of the single-disk type and in the A construction are slightly larger than the Type V-2-A due to a larger terminal chamber which provides for eight current and seven potential terminals, made necessary by the wide scope of application possible with these meters. Potential indicating lamps are also added.

Type V-3: 3-wire, 2- and 3-phase; also 4-wire, 2-phase. See Fig. 14-7.

Type V-5: 4-wire wye, 3-phase.

Type V-6: 4-wire delta, 3-phase.

Type V-8: 5-wire, 2-phase.

The meters are manufactured in the A construction for bottom connections and in the S construction for socket mounting.

Type V-series—Three Element

These meters have been reduced in size over former 3-element meters. They have only two disks. The elements are the same as in other meters in the Type V series and are arranged so that two elements act upon a lower disk and a third upon an upper disk. Potential indicating lamps are provided.

Type V-4-A: 4-wire wye, 3-phase. See Fig. 14-8.

Type V-7-A: 4-wire delta, 3-phase.

Type V-9-A: 3-wire, 3-phase; and 2-wire, single-phase.

Type V-10-A: 3-wire, 3-phase; and 3-wire, single-phase.

Switchboard Meters

Type IS-series—One Element

The Types IS-6 and IS-7 are 25-cycle, single-phase switchboard meters similar to the Type I-15.

The Types IS-8, IS-9, IS-10 and IS-11 single-phase switchboard meters

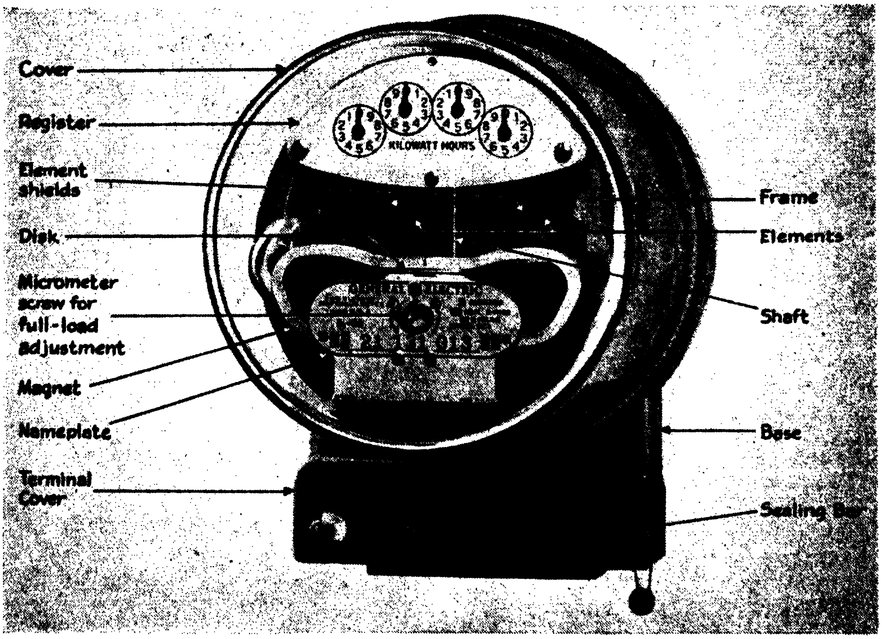


Fig. 14-6. Type V-2-A Two-element Watthour Meter

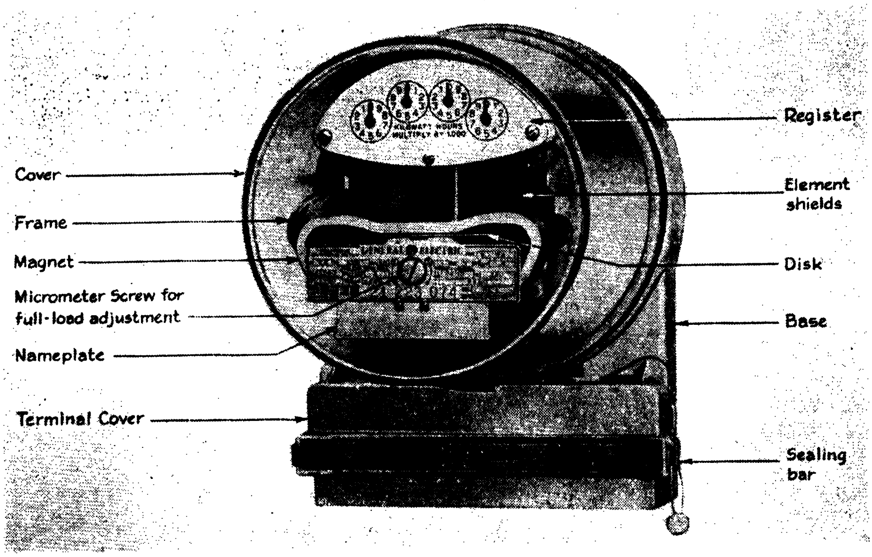


Fig. 14-7. Type V-3-A Two-element Watthour Meter

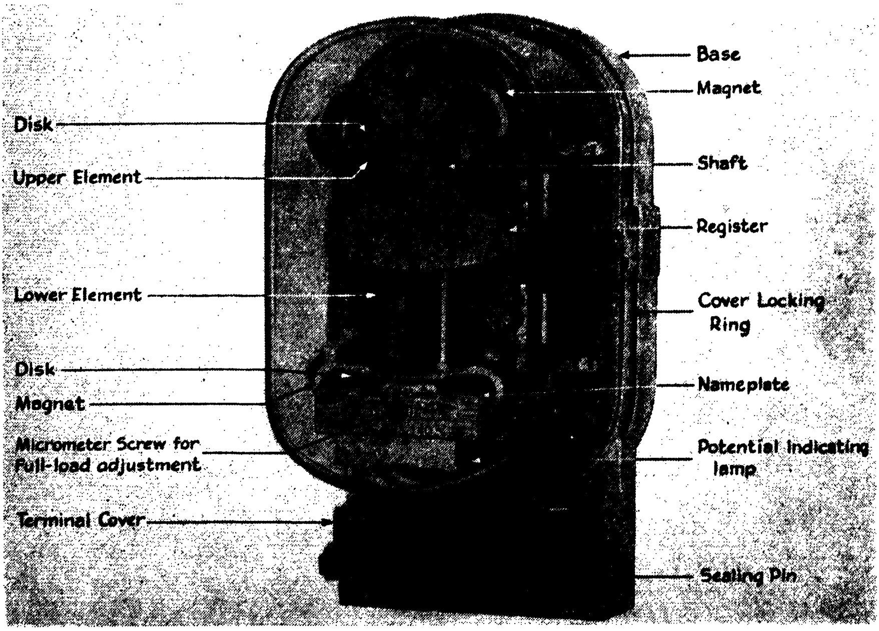


Fig. 14-8. Type V-4-A Three-element Watthour Meter

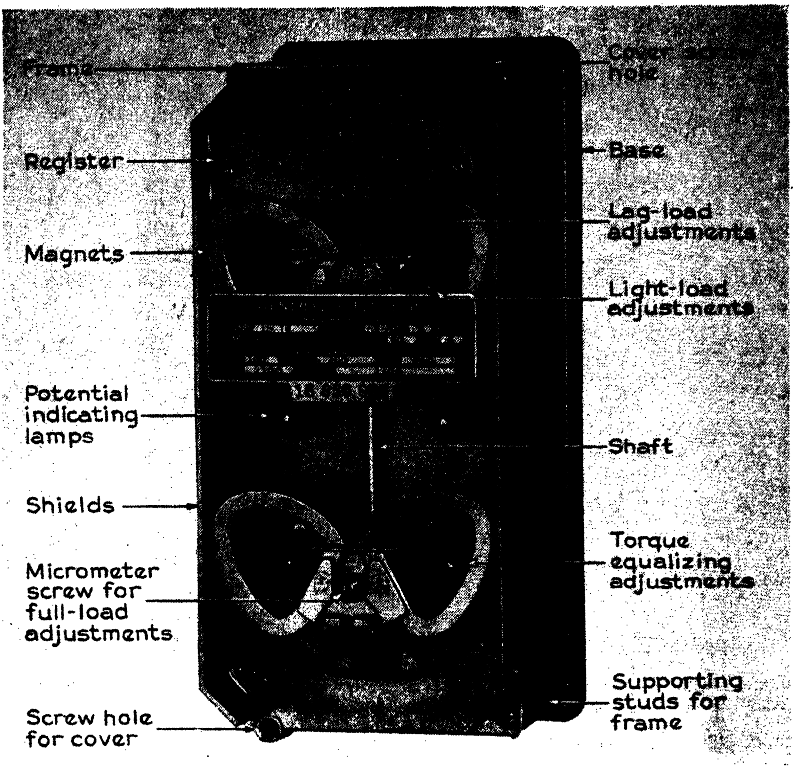

Frame
Cover screw hole
Register
Base
Lag-load adjustments
Magnets
Light-load adjustments
Potential indicating lamps
Shaft
Shields
Torque equalizing adjustments
Micrometer screw for full-load adjustments
Supporting studs for frame
Screw hole for cover

Fig. 14-9. Type DS-19 Two-element Watthour Meter, covers removed

differ in the construction of covers, terminals, and bases. These meters have elements similar to the Type I-16.

Type DS-series—Two and Three Element

The Types DS-11 and DS-12 are 25-cycle, two-element switchboard meters similar to the Type D-8.

The Types DS-9 and DS-13 are three-element switchboard meters similar to the Types D-9 and D-13.

The Types DS-19 (Fig. 14-9), DS-21, DS-34, DS-38 and DS-40 are two-element switchboard meters and have elements similar to the Type D-14 meter. Comparable three-element types are DS-20, DS-23, DS-35, DS-39 and DS-41. The various types differ in mounting arrangement as follows:

Type Designation		
Two Element	*Three Element*	*Mounting*
DS-19	DS-20	Surface
DS-21	DS-23	Surface, with test facilities
DS-34	DS-35	Semiflush
DS-38	DS-39	Draw-out, Semiflush
DS-40	DS-41	Draw-out, Surface

Instrument Transformer Rated Meters

All alternating-current meters except the Types I-18 and V-2 have been manufactured for use with either current transformers, potential transformers, or both. The Types I-16, I-20, D-14, D-15 and the corresponding switchboard meters are usually rated at 2.5 amperes when used with current transformers having a 5-ampere secondary rating. This also

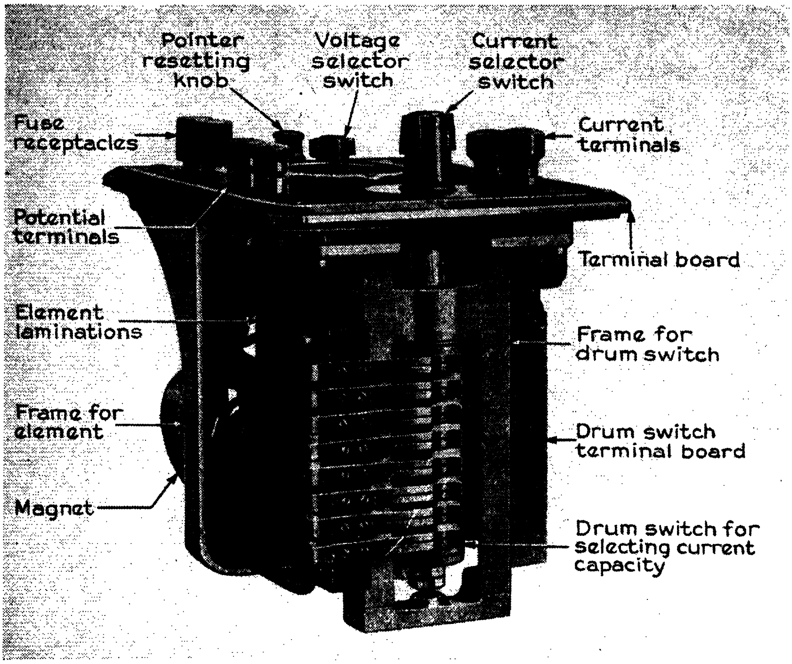


Fig. 14-10. Type IB-8 Portable Watthour Meter Standard, removed from case

applies to the meters Type V-3 to V-10 inclusive.

The speed and register ratio of a 2.5-ampere meter is double that of a 5-ampere meter, and the test constant is one-half.

PORTABLE STANDARD WATTHOUR METERS

Single-phase, portable watthour meter standards are designed to provide the high, sustained accuracy required for system testing. Each standard is carefully calibrated and a certificate of performance issued. Carrying cases are equipped with removable carrying straps, and a potential circuit switch is supplied.

External connections are made by means of terminals on the top of the standard. The dial face has one main dial of 100 divisions and two sub-dials of ten divisions. The main dial sweep hand is coupled directly to the disk shaft. The sub-dials register revolutions of the sweep hand. A reset device returns the pointers to zero.

Standards are manufactured with single or double voltage ratings (25 or 60 cycles) and in several current combinations. For double voltage rating, a selector switch is provided. Standards manufactured since April, 1925, have Class I temperature compensation.

Type IB-7

The adjustments are the same as in the Type I-14 meter, and the permanent magnets are similar to those used in the Type I-16 meter. Current coil ratings are 1, 5 and 20 amperes.

Type IB-8

This standard is similar to Type IB-7 except that it is larger and has current coil ratings of 1, 5, 10, 25 and 50 amperes. Fuses protect the 1- and 10-ampere coils. A switch is provided for changing from one current rating to another. Current coil ratings of 1, 5, 10, 50 and 100 amperes have also been furnished. See Fig. 14-10.

Type IB-9

This standard supersedes Type IB-7. It has improved performance characteristics. Class I and II temperature compensation, micrometer-screw light load adjustment and vernier full load adjustment in which one turn will change the calibration 0.1 per cent. Current coil ratings are 1, 5 and 25

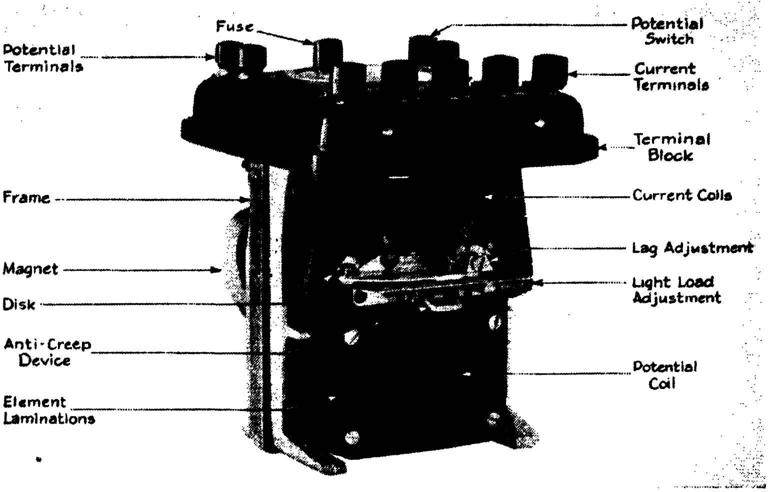


Fig. 14-11. Type IB-10 Portable Watthour Meter Standard, removed from case

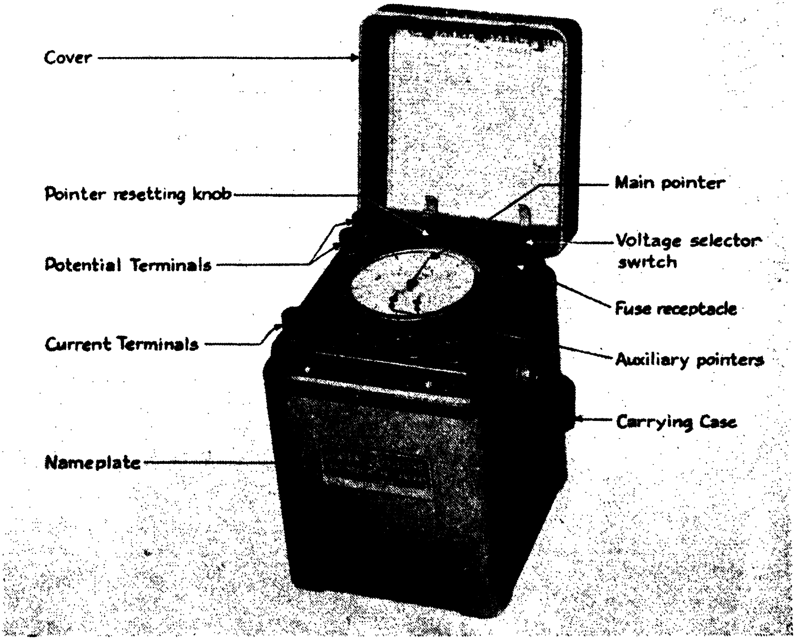


Fig. 14-12. Type IB-10 Portable Watthour Meter Standard

amperes, and due to increased thermal capacity may be used on loads up to 50 amperes.

Type IB-10

This standard is similar to Type IB-8 which it supersedes. The performance characteristics have been still further improved. The dial and pointer construction is of the anti-parallax type. Current coil ratings are 1, 5, 12.5, and 50 amperes with thermal capacities such that the standard may be used on loads up to 100 amperes. See Figs. 14-11 and 14-12.

SPECIAL METERS

Many types of meters for special purposes are manufactured, but only those most frequently used are described.

Type IR-20-A—One Element
Type IR-20-S—One Element

In these types the watthour meter is provided with a special register and time switch combined within the base and special cover of the meter. The watthour meter element is the same as the Type I-20.

Type IR-30-A—One Element
Type IR-30-S—One Element

These types are the same as the Type IR-20 except that the watthour meter element is that of the Type I-30. See Fig. 14-13.

The combination watthour register and time switch is supplied in three forms.

The Type T-28 combines a single four-dial meter register with a time switch, each performing its function independently of the other. The Type T-29 combines a double four-dial register with a time switch which automatically transfers the registration of the meter from one set of dials to the other at predetermined times and also opens and closes an external load circuit. Fig. 14-14.

The Type T-30 combination is the same as the Type T-29 except the switch contacts for control of an external circuit have been omitted.

Watthour meters combined with time switches and special registers are used in connection with the measurement of on and off peak loads and for

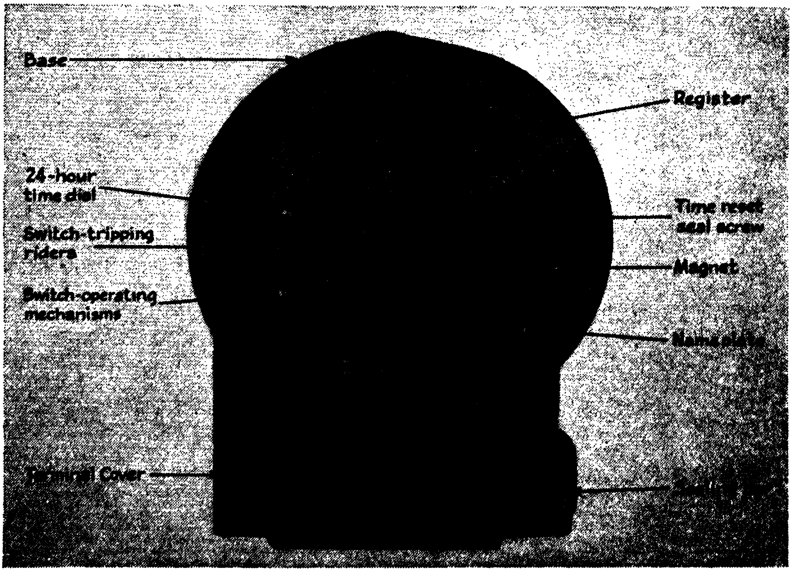


Fig. 14-13. Type IR-30-A Combination Watthour Meter and Time Switch

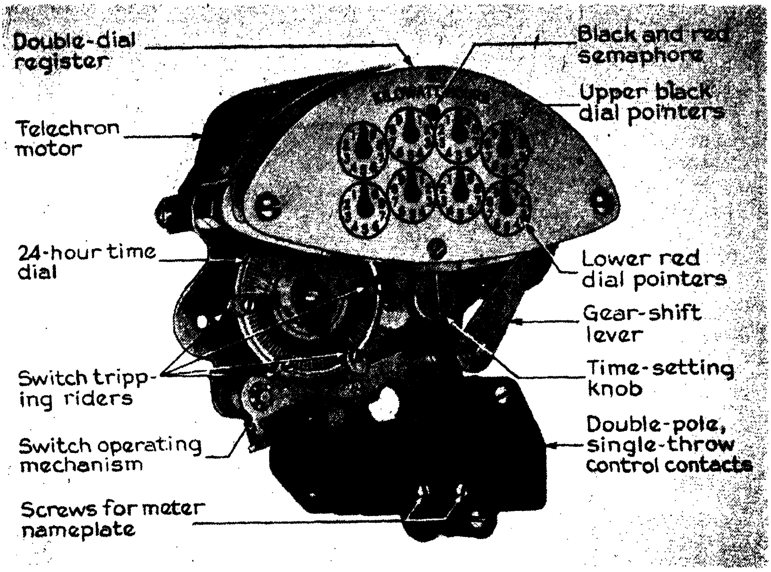


Fig. 14-14. Type T-29 Combination Double-dial Watthour Meter and Time Switch Register

controlling water heater and similar circuits.

Totalizing Watthour Meters

These meters are designed to totalize a number of circuits, generally polyphase, and are often used in generating stations. A meter element for each phase of each circuit is provided and acts upon disks on a common shaft which drives a single register. This arrangement may be duplicated, utilizing two shafts which drive a common register. All are designed for switchboard mounting.

Autotransformers

Autotransformers are used with

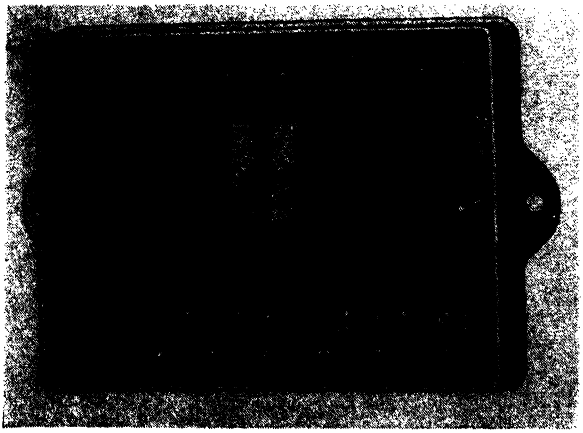


Fig. 14-15. Types MC-1 and MC-3 Autotransformers, covers removed

watthour meters for the purpose of measuring kilovar-hours or kilovolt-ampere-hours. See Fig. 14-15, 14-16 and 14-17. Types MC-1, MC-2, and MC-7 autotransformers are used for kilovar-hour metering to provide voltages to the watthour meter which are displaced 90 degrees. Types MC-3, MC-4 and MC-5 autotransformers are used for kilovolt-ampere-hour metering to provide voltages which are displaced by an angle corresponding to the average power factor of the circuit. Type MC-7 is similar to MC-1 except a test switch is provided with the device. Type MC-5 is similar to Type MC-3 except taps are provided for three power factors. The application and connections of autotransformers are described in Section 6.

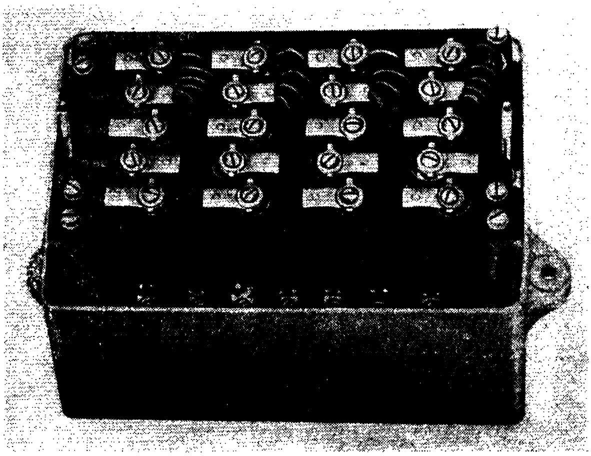


Fig. 14-16. Type MC-5 Autotransformer, covers removed

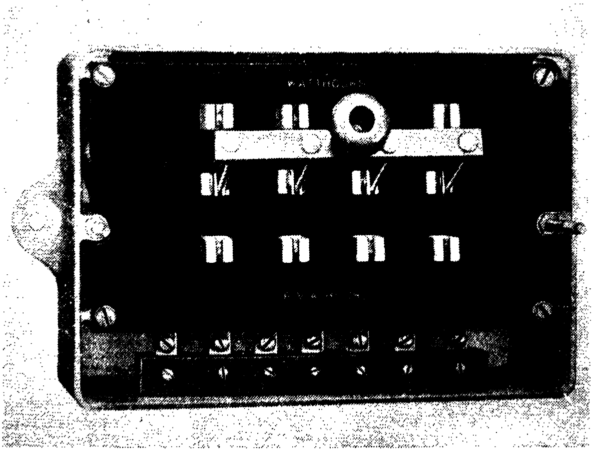


Fig. 14-17. Type MC-7 Autotransformer, covers removed

METER BEARINGS

Pivot Type Bearings

The pivot type consists of a pivot which is screwed into the bottom of the disk shaft and an oiled sapphire jewel, mounted in a removable screw in the meter frame.

The oil-tight jewel screw, Fig. 14-18, has provisions for holding a much greater quantity of oil than the older types so that the total surface exposed to the air for evaporation and volatilization is small compared to the total volume of oil.

Ball Type Bearings

This type consists of a ball bearing

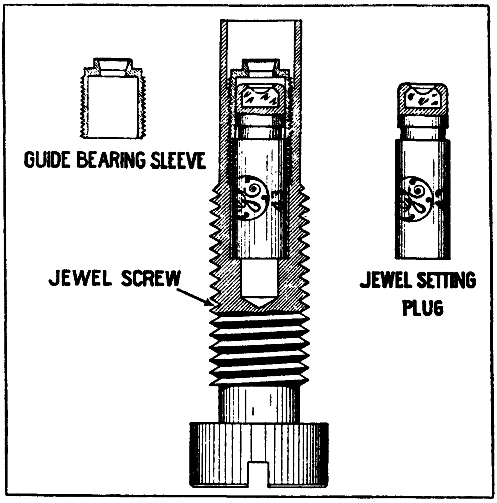


Fig. 14-18. Oil-tight Jewel Screw for Watthour Meters

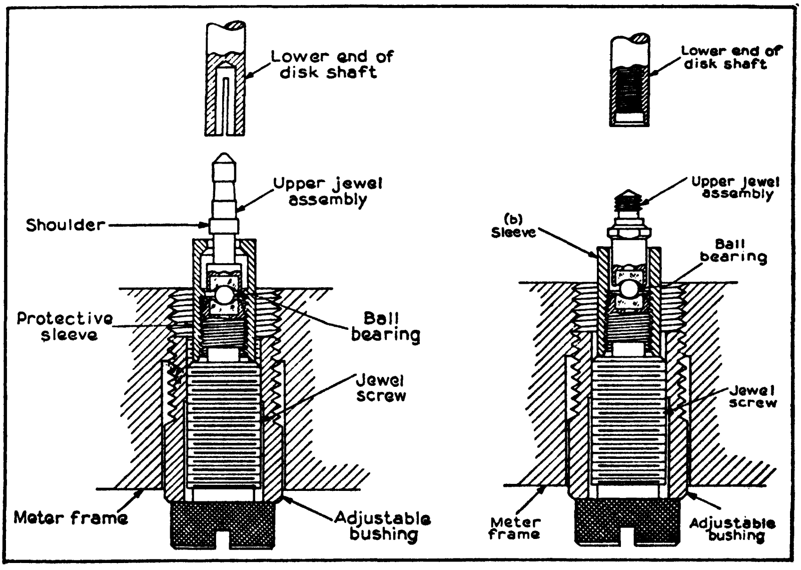


Fig. 14-19. Ball Bearing for Watthour Meters

held between an upper and lower sapphire jewel. This type of jewel is supplied both with and without a protective sleeve as shown in Fig. 14-19. No lubrication is required with this type of bearing.

Either the oil-tight type or the ball-bearing type is supplied in modern meters.

The upper bearing consists of a non-oxidizing guide pin mounted in an adjustable top-bearing plug and a guide bushing set in the top of the disk shaft.

INDICATING DEMAND REGISTERS

Each of these devices is fundamentally a complete demand meter embodied in a watthour register for use on General Electric a-c watthour meters. They are of the block-interval type, integrating and averaging the demand over a definite time interval. Kilowatthour consumption is recorded by means of conventional dials and pointers. In registers of the sweep-hand construction, the maximum kilowatt demand is indicated by a friction pointer and scale. In registers of the cumulative-dial construction, the maximum demand for each reset period is added to the cumulative reading by means of a set of dials and pointers.

Type M-10 Register

This demand register superseded the Type M-9 and differed from it mainly in that a disk-type synchronous motor was used in place of a constant-speed induction motor for interval timing.

Type M-14 Register

This demand register was an improved and more rugged device with increased operating forces. It superseded the Type M-10 and was superseded by the Type M-20.

Type M-20 Register

This demand register is of an entirely different construction from preceding types. It has a longer scale, is more rugged in construction and has been improved to insure greater reliability. See Fig. 14-20.

Operating Principle—The worm wheel meshes with a worm on the watthour-meter shaft and through the worm shaft drives the kilowatthour and demand gear trains. The kilowatthour dials are driven by a simple gear train consisting of the worm wheel and the group of gears shown just back of the dial plate. See Fig. 14-21.

The demand gear train consists of the clutch-shaft assembly and the pointer-pusher shaft assembly. The clutch-shaft is driven by the worm wheel, which is fastened to the shaft, and through the gears as shown in Fig. 14-21, thus driving the pointer up the scale.

During the demand interval the motor, through its gear train, is driving a timing disk one revolution, and is also winding the reset spring. At the end of the interval the ear on the timing disk trips the resetting mechanism,

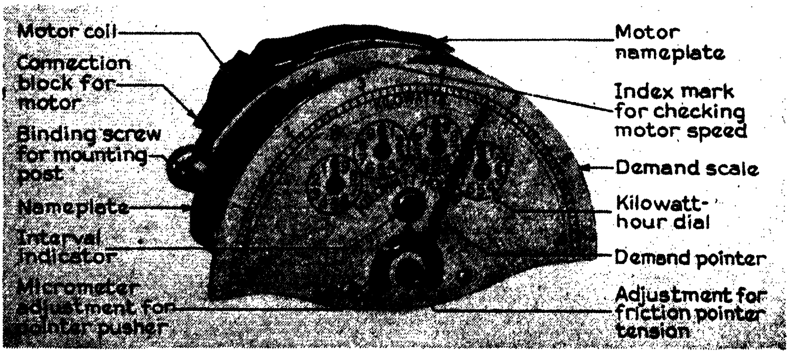

Motor coil
Connection block for motor
Binding screw for mounting post
Nameplate
Interval indicator
Micrometer adjustment for pointer pusher
Motor nameplate
Index mark for checking motor speed
Demand scale
Kilowatt-hour dial
Demand pointer
Adjustment for friction pointer tension

Fig. 14-20. Type M-20 Demand Register

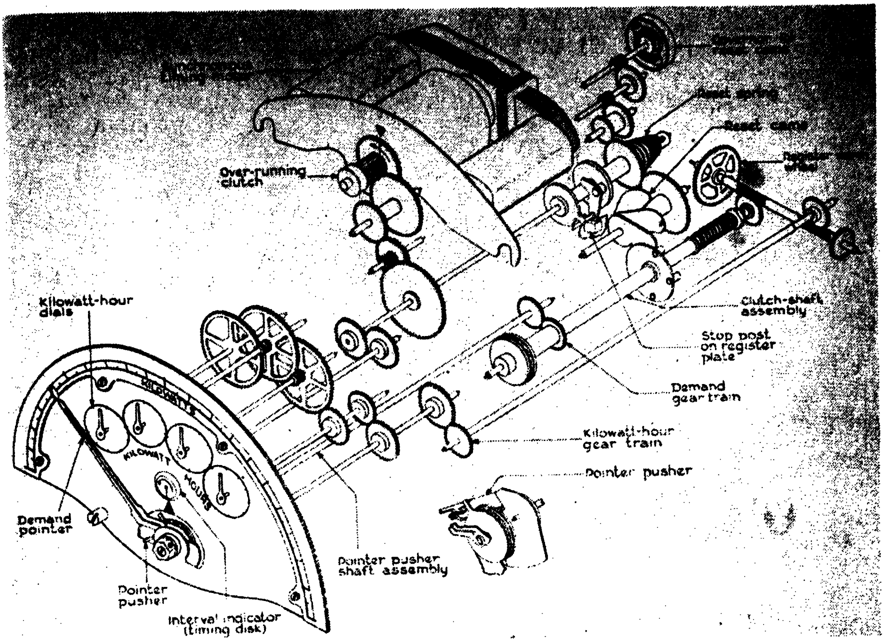


Fig. 14-21. Type M-20 Demand Register—Schematic Diagram

which is actuated by a governor-controlled spring, resetting the pointer pusher to zero. The pointer is held by friction at the highest position to which it has been driven, and is reset manually.

Gears on the motor shaft and on the worm-wheel shaft are for use in connection with a checking device.

Design Features—In the Type M-20 register an improved high-torque Telechron motor is used for timing. The entire motor may be lifted out of the register by releasing two screws. The motor is equipped with suitable index marks so that a quick check of its speed can be made. All rotor units for these motors are interchangeable and have removable caps which permit replenishing the oil.

Resetting is of the positive *follow-up* type in which the action of the motor follows that of the resetting spring and forces the pointer pusher to zero in the event any abnormal condition of friction has obstructed its operation. This assures against over-registration due to faulty reset.

The register is designed with large factors of safety in the clutch and pointer friction values. The scale is 6¼″ long, distributed over an arc of 180 degrees.

An over-running clutch on the motor shaft permits manual reset of the register independently of the motor at any time. This feature permits making an overall accuracy check in about one minute through the use of a portable self-checking adapter for manual operation. A small indicator on the front of the dial shows at a glance the part of the interval used, and that which remains. The pointer pusher is visible through a circular aperture at the center of the dial.

Scale and Register Classes — The scales for M-20 registers have been selected to provide ample capacity for any load which might normally be placed on a watthour meter of a given rating and to minimize the loss of inherent accuracy due to low readings on scales having excessive capacity. To permit full utilization of the overload capacity of modern watthour meters, the full scale ratings are approximately equal to 3 times the rating of single-phase meters, and 2.5 times the rating of polyphase meters. Complete information on scale ratings for different register ratios is given in Table 14-K.

The different overload values require different demand gear trains and these are identified by class letters which appear on the register name plate. As long as the register ratio, dial and scale multiplier, demand interval, voltage, and frequency are correct for a given meter rating, all classes of registers will indicate correct and like demand, but the angular deflections will differ. The class of register for which the pointer will have a reasonably high deflection, with adequate overload capacity, is generally selected.

A register does not change from one class to another by applying only the correct demand scale for the given class. The gear reduction of the train of gears which drives the pointer pusher must likewise be changed. For each class of register and demand interval, there is a definite gear reduction from the register worm wheel to the pointer pusher. This is expressed in Table 14-L as the number of revolutions of the register worm wheel for full scale (180 degrees or ½ revolution) of the pointer pusher.

Universal Registers—Universal registers have been built in the classes described above. The ratio of a universal register is 166 2/3 and it may be used on any type of meter of any rating by using a multiplier for both the kilowatthour and demand readings. The multiplier is generally a whole number and is obtained as follows:

$$\text{Dial and Scale Multiplier} = \frac{\text{Watthour Constant}}{0.6}$$

A detachable multiplier plate is furnished with each register on which the multiplying constant may be printed.

Type M-21 Register

This demand register is similar to the M-20 register and differs in that the cumulated value of the sum of the maximum demands of the previous

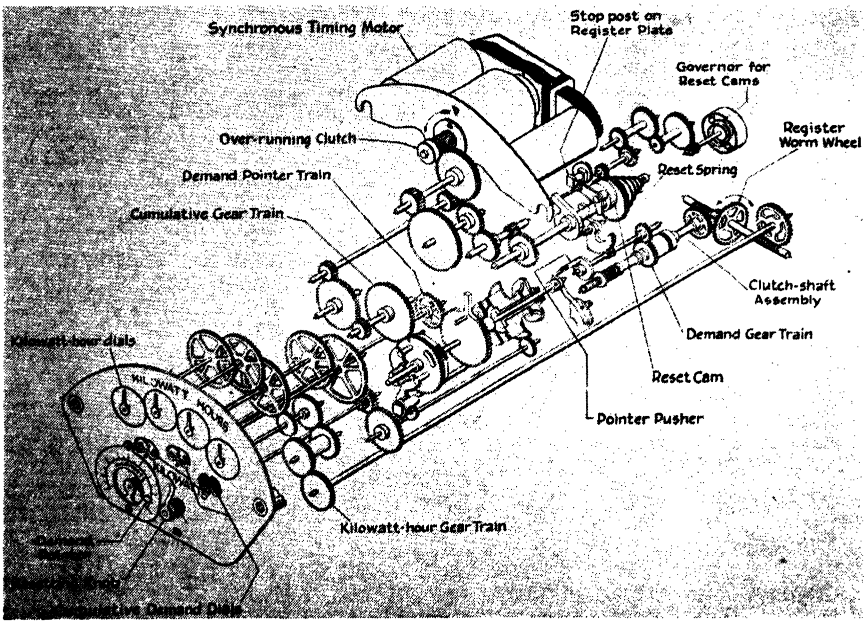


Fig. 14-22. Type M-21 Demand Register—Schematic Diagram

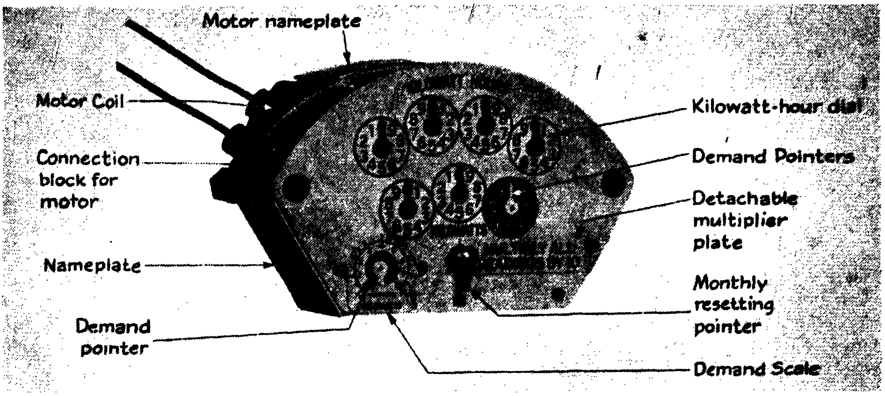


Fig. 14-23. Type M-21P Cumulative Demand Register

reading periods is indicated prior to resetting. When the demand meter is reset, the maximum demand value is added to the cumulative reading. The value of the maximum demand for the present reading period is the difference between the present reading and the previous reading of the cumulative dials. See Fig. 14-22.

Scales and Dials—The full-scale deflection is limited by the travel of the pointer pusher and the demand pointer. The actual scale kw values vary with the register ratio, and the register ratio depends upon the type and rating of the meter on which the register is used.

Because of the higher reading accuracy of cumulative-demand dials only two *classes* (demand mechanism gear ratios) are used for both single and polyphase meters. Likewise, as the ratio of full-scale kw to meter rating may be made somewhat greater than for corresponding types of indicating, sweep-hand demand registers, this ratio on the M-21 class F is approximately 11% higher than M-20 registers on single-phase meters, 60% higher on two-element polyphase meters, and 37% higher on three-element meters. Scale ratings for various register ratios are given in Table 14-M.

The small, 270-degree arc demand scale in the lower left-hand corner of the M-21 front plate is intended for approximate demand indication only, since actual demand readings are taken from the three cumulative demand dials in the center of the front plate. These dials are connected to the demand mechanism by suitable gearing to insure that for any register ratio the rotation of the dials gives the correct kw change in dial readings. The right-hand or fastest moving dial never rotates less than five nor more than fifty revolutions when the register is reset from full scale position. To obtain this condition the kw value of each division on the right-hand and middle cumulating dials is sometimes changed and the cumulating gearing made to agree. Registers in ratios up to and including 6 2/3 (120 kw down to 50 kw scale) use all three white cumulative dials with black numbers; so one revolution of the fastest moving dial is equal to 10-kw demand (disregarding dial multiplier), and the dials will read 999 kw before repeating. Register ratios from 6 17/18 to 66 2/3 inclusive (48 kw down to 5.0 kw full scale) use two white dials and one black dial. The right-hand or fastest moving dial is black with white figures, and one revolution equals 1.0 kw demand. This combination of dials will read 99.9 kw before repeating. All ratios including and above 69 3/13 (4.8 kw down to 1.0 kw full scale) use one white dial and two black dials. One revolution of the black right-hand dial is equal to 0.1 kw, and one revolution of the black middle dial is equal to 1.0 kw. This combination of dials will read 9.99 kw before repeating.

Form P Registers — These demand registers differ from the described construction in that the dials for the cumulative demand are stationary (printed on the register front plate), and the pointers rotate. This feature involves different register front plate, scale, and shafts (with pointers). These are, however, the only differences between the two constructions. See Fig. 14-23.

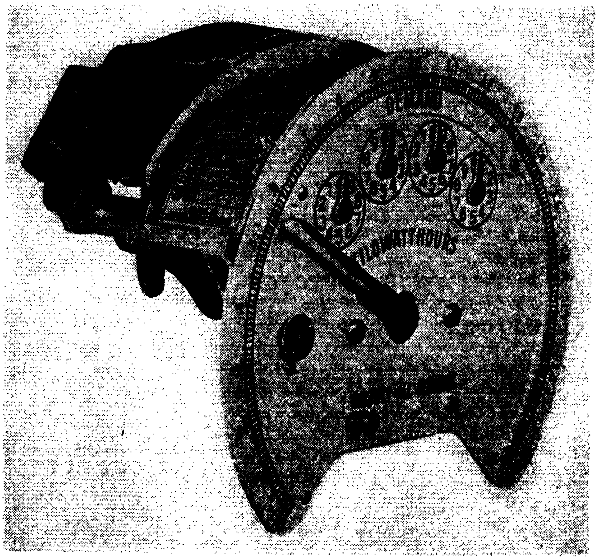


Fig. 14-24. Type M-30 Demand Register

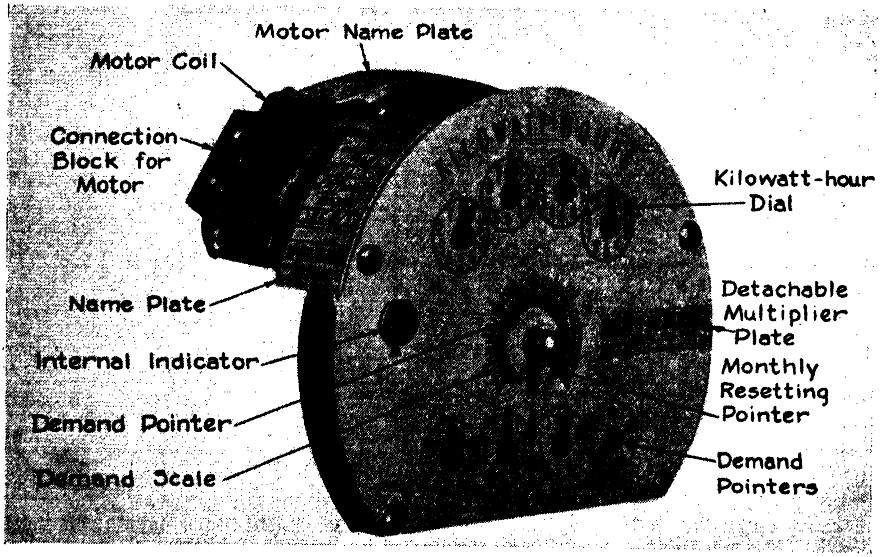


Fig. 14-25. Type M-31 Cumulative Demand Register

Type M-30 Register

This demand register (Fig. 14-24) is similar to the M-20 indicating demand register and differs in that the interval reset operation is performed by the motor through a *Geneva* mechanism, which in turn resets the pointer to zero. The interval reset mechanism, the two classes of demand scales and the scale ratings are the same as for the Type M-31. The latter are given in Table 14-N.

Type M-31 Register

This demand register (Fig. 14-25) is similar to the M-21P register and differs in that the interval reset operation is performed by the motor through a Geneva mechanism, Fig. 14-26.

Scales and Dials — There are two classes of demand scales, Class 1 and Class 2 corresponding to 166 2/3% and 333 1/3% of the full-load rating of the meter respectively. Scale ratings for various registers are given in Table 14-N. There are four cumulative demand dials at the bottom of the front plate.

RECORDING WATTHOUR DEMAND METERS

These meters (Fig. 14-27) combine in one device a watthour meter and a recording demand meter. The demand mechanism is of the "block-interval" type, recording on a strip chart the demand integrated over a definite demand interval. A record or line is made on the chart for each interval.

The basic meter elements drive not only the standard watthour registers but also the recording pen. The length of the line recorded by the pen on the strip chart is, therefore, proportional to the kilowatthours integrated during a specified time and, because the time is constant, the length of the line is proportional to the average kilowatts of the load during the demand interval, or the kilowatt demand.

Operating Principle—The watthour meter disk shaft, in addition to driving the watthour register, also drives the inking pen, through a suitable gear train and clutch, by means of a second worm located between the meter disks. The clutch is "slipped" when the pen

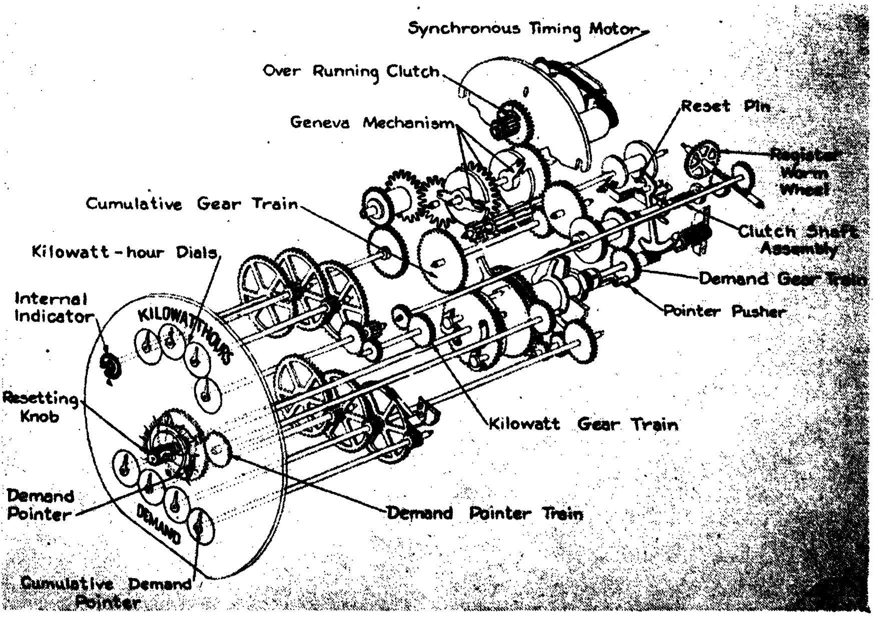


Fig. 14-26. Type M-31 Demand Register—Schematic Diagram

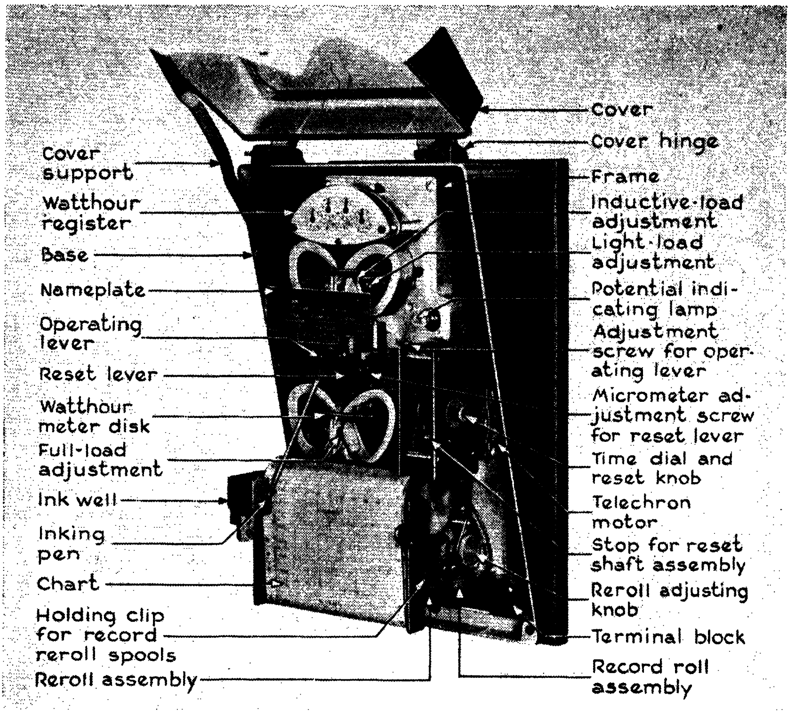


Fig. 14-27. Type DG-1 Two-element Recording Watthour Demand Meter

is reset at the end of the demand interval by the resetting spring-actuated mechanism.

The time dial is calibrated to indicate what part of the demand interval has elapsed and what part remains.

A Telechron motor winds the resetting spring and also drives the chart continuously at a uniform rate. The driving drum is geared to the Telechron motor through a suitable gear train and clutch which permits advancing the chart manually by turning the drum.

Each time the pen is returned to zero—at the end of the demand interval—ink is supplied to the pen from the inkwell. The ink is drawn by capillary action to an aperture at the upper end of a glass tube in the inkwell.

Types DG-1, DG-3 and DG-5

These meters are of the two-element type using essentially the electric elements of the Type DS-19 watthour meter. Types DG-3 and DG-5 differ from the DG-1 in the construction of covers, cases, and terminals.

Types DG-2, DG-4 and DG-6

The Type DG-2 is similar to the Type DG-1, except that it has three elements. Types DG-4 and DG-6 differ from the DG-2 in the construction of covers, cases, and terminals.

The DG meters may be provided with a top bearing detent, alarm contact device, heating element and separate Telechron motor terminals. The top bearing detent is used to prevent negative registration. The alarm contact is used to operate a signal when the demand reaches a predetermined value. The heating element is for use in meters which may possibly be operated below a minimum recommended temperature. Separate motor terminals are for use where the meter is connected with autotransformers to measure kvar or kva demand. These terminals permit connection of the Telechron timing motor to a separate source of supply.

The standard charts are calibrated in *secondary* kilowatts demand, and the records must be multiplied by a constant for converting to *primary* kilowatts demand. This constant is the ratio of primary to secondary energy, which for standard circuits is the product of the current and potential transformer ratios.

The meters are arranged for either front or back connections.

CONTACT-OPERATED, INDICATING DEMAND METERS

These demand meters are used in connection with a watthour meter equipped with a contact device to indicate the maximum kilowatt demand by means of a friction pointer and scale. They are of the block-interval type, integrating and averaging the demand over a definite demand interval.

Operating Principle—Fig. 14-28 illustrates the basic operating principle. Electrical impulses transmitted by the contact device at a rate proportional to the load on the watthour meter disk momentarily energize an operating electromagnet within the demand meter. This electromagnet through its armature, pawl, pointer pusher, and suitable reduction gearing advances the friction pointer over the scale. After each impulse the armature is returned to its de-energized position either by a spring or force of gravity as in Fig. 14-30, by a permanently excited electromagnet, or an electromagnet controlled by the contact device as in Fig. 14-28, depending upon the individual type or form of a particular type.

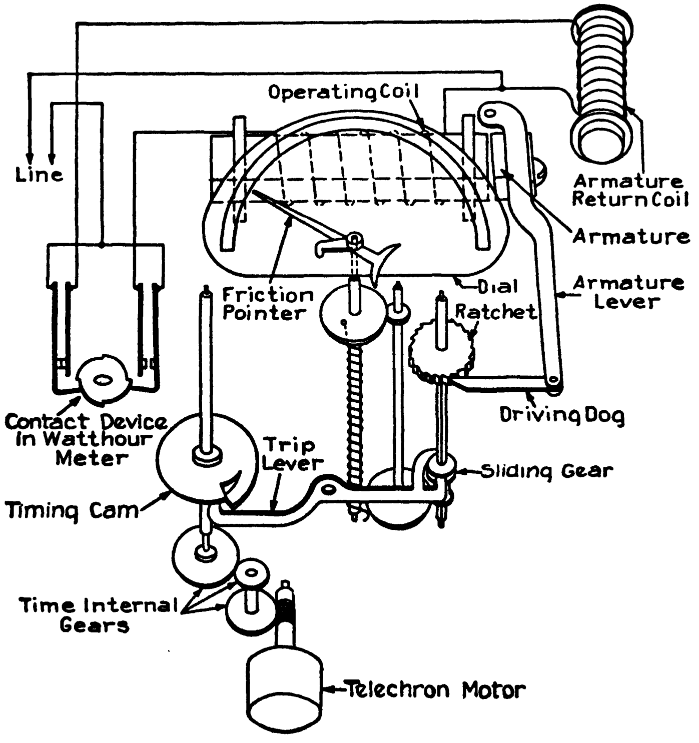


Fig. 14-28. Type M-16 A-C Demand Meter—Schematic Diagram

In meters for a-c service a constant-speed motor drives the resetting mechanism and governs the demand interval. The motor is geared to the timing cam as shown in Fig. 14-28.

In meters for d-c service a spring-driven clock, either hand-wound or motor-wound, drives the resetting cam and governs the demand interval. The motor may be either a d-c commutator-type motor or an impulse motor.

Meters in which the armature of the operating magnet is returned to its de-energized position by a spring or permanently excited electro-magnet are for use with two-wire contacts. Those in which the armature is returned through electrical impulses are for use with three-wire contacts.

Meters of the Type M series arranged for back connections are designated Type MS. With the exception of the case, terminals and mounting facilities, corresponding meters of both types are the same.

Type M-11 Demand Meter A-C

This demand meter supersedes the Type M-4 and is for use with two- or three-wire contacts depending upon the construction of the individual meter. Its demand gear train is actuated by a U-type electromagnet, the armature of which is returned to its de-energized position after each operation by a restoring electromagnet, permanently excited when the meter is for use with two-wire contacts, and impulse-excited when the meter is for use with three-wire contacts. A constant-speed induction shaded-pole motor drives the resetting mechanism and governs the demand interval.

Type M-12 Demand Meter D-C

This meter supersedes Type M-6. It operates on the same principle as the Type M-11 a-c meter. The timing motor has a permanent magnet field.

Type M-13 Demand Meter A-C

This demand meter supersedes the Type M-11. It differs therefrom principally in that the restoring magnet and terminals are of an improved design.

Type M-15 Demand Meter D-C

This demand meter supersedes the Type M-12 and differs therefrom principally in that certain of the clock staffs have jeweled bearings.

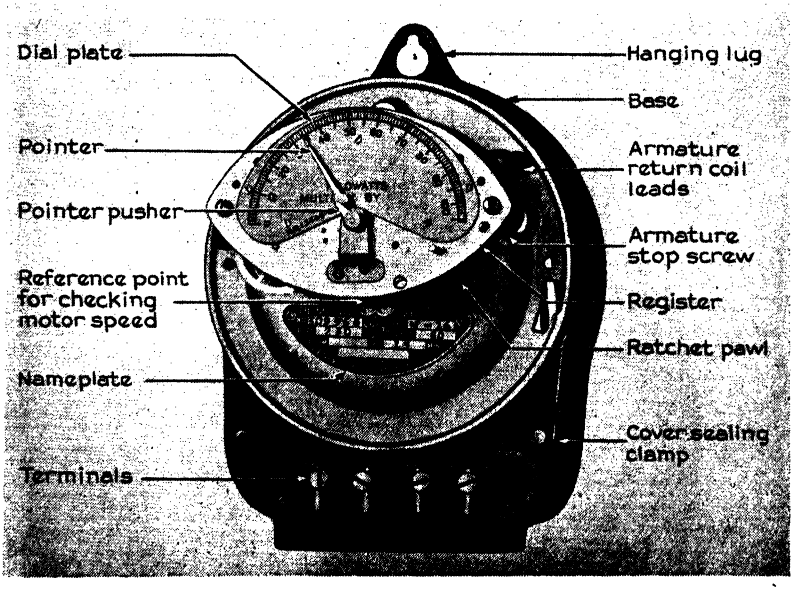


Fig. 14-29. Type M-16 A-C Demand Meter, covers removed

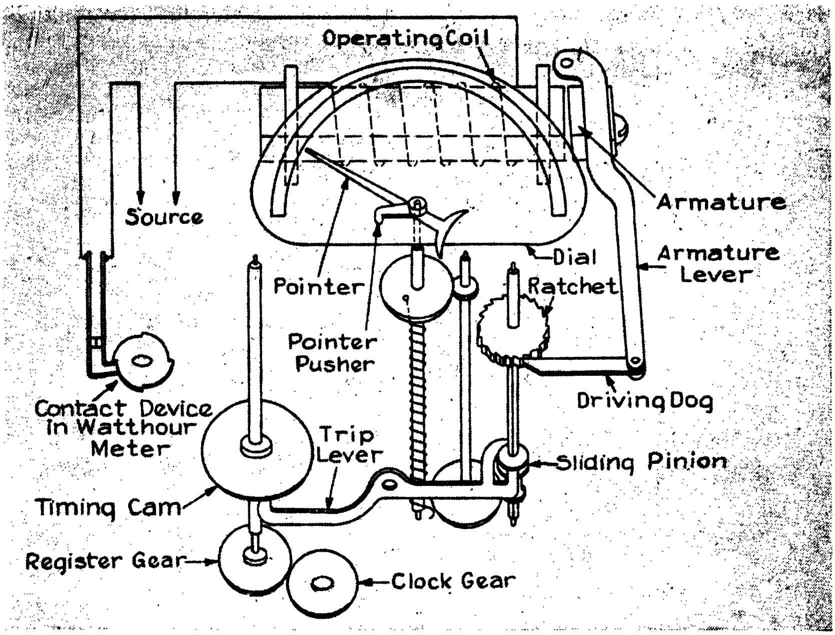


Fig. 14-30. Type M-17 D-C Demand Meter—Schematic Diagram

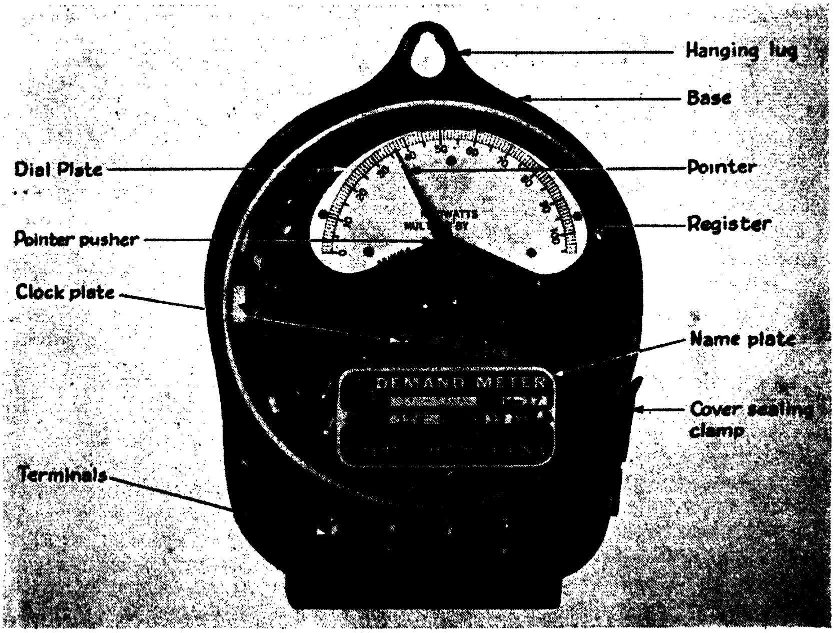


Fig. 14-31. Type M-17 D-C Demand Meter, terminal cover removed

Type M-16 Demand Meter A-C

This demand meter supersedes the Type M-13 and differs from it principally in that the induction disk type of motor is replaced with a Telechron synchronous motor, and that it is in a new-design base and cover. See Fig. 14-29.

Type M-17 Demand Meter D-C

This demand meter (Fig. 14-31) operates on the same principles as the Type M-16 a-c meter. The timing mechanism is a spring-driven clock, motor wound. The timing cam does not rotate continuously but is released at the end of the interval and is driven one revolution by the clock spring. This is accomplished in less than one second and the time elapsing between the demeshing and remeshing of the sliding pinion with the gear it drives is negligible. See Fig. 14-30.

Design Modifications—Meters of the duplex form are equipped with operating mechanisms requiring 212 impulses to advance the pointer to full scale and have a two-section advancing coil to totalize the demand of two metered circuits. These meters use either a spring or a permanently excited electromagnet for returning the operating magnet to its de-energized position after each operation. They are designated as Form D-2.

The MS series are the switchboard-mounted equivalent of the M series.

Meters equipped with an alarm contact to operate a signal when the demand has reached a predetermined value are designated as Form A. These meters do not have a pointer. The pointer pusher actuates the contacts.

Meters equipped with a thermostatically controlled heating unit to extend the operating range to below 0 F ambient, are designated as Form T.

Meters equipped with permanently excited electromagnets are designated as Form E.

Scales—Standard scales are calibrated to indicate the number of advancing impulses registered. The calibration is 0 to 104 in the simplex meters and 0 to 208 in duplex meters. The indication of the pointer must be multiplied by a constant for converting to kilowatts demand.

In addition to the standard arbitrary calibrated scales, there are scales calibrated to read directly in kilowatts demand.

CONTACT-OPERATED, GRAPHIC DEMAND METERS

Each meter of the Type G series is for use with a watthour meter equipped with a contact device. It records the kilowatt demand on a circular chart together with the day and time of day at which the separate demands occurred. Usually the kilowatt demand is recorded in an arbitrary value, and it is necessary to multiply this value by a constant to obtain the actual kilowatt demand. The meter is of the block-interval type, integrating the demand over a definite demand interval.

Operating Principle—In service the device is electrically connected to the watthour meter through a contact device operated by the watthour meter disk shaft at a rate proportional to load on the meter. As the watthour meter disk rotates, this contact device makes and breaks an electrical circuit to momentarily energize an operating electromagnet within the demand meter. The electromagnet operates a ratchet and pawl mechanism to move the stylus over the circular chart. See Fig. 14-32.

After each operation of the electromagnet its armature is returned to the de-energized position either by means of a spring, a permanently excited electromagnet, or an electromagnet controlled by the contact device, depending upon what construction is used. In Fig. 14-32, the return coil is controlled by the contact device.

When the end of each demand interval is reached, a cam in the resetting mechanism has rotated to a position where one arm of a compound trip lever falls and causes a sliding pinion to disengage from the gear with which it meshes. This opening of the gear train allows a spring to return the stylus mechanism to its starting posi-

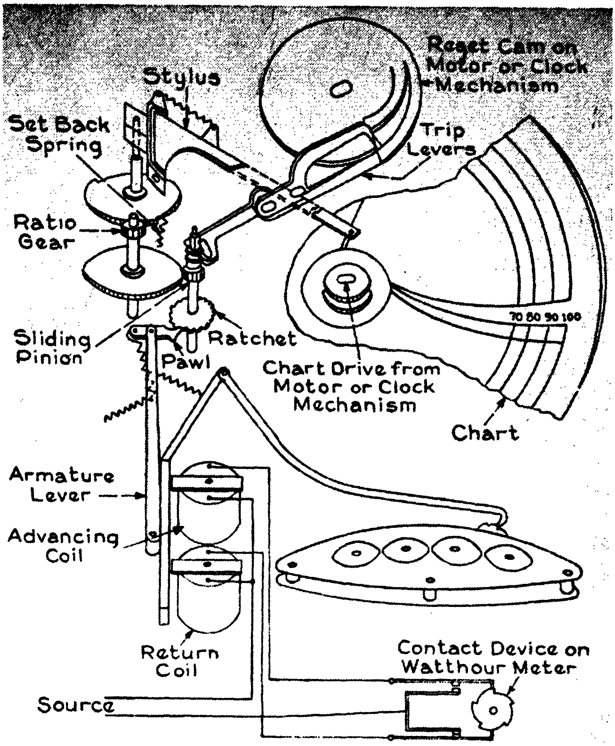


Fig. 14-32. Type G-9 Graphic Demand Meter—Schematic Diagram

tion. A slight further rotation of the cam permits a second arm of the compound trip lever to fall. This action allows the sliding pinion to re-engage the gear it drives and re-establishes the gear train from the armature to the stylus.

The paper chart as well as the demand interval mechanism is driven either by a spring-driven clock or a Telechron motor. Two general designs are employed for the mechanism driven by a Telechron motor. In one design the chart is driven at a single rate of speed, while in the other the chart may be driven at either one of two rates of speed depending upon the setting of a gear shift lever. Where the chart is driven at a single rate of speed, the gearing may be such that the chart makes one complete revolution in one, seven, sixteen, or thirty-two days. In mechanisms equipped with a gear shift, the chart speed combinations may be 1/7, 7/32 or 16/32 days. The timing mechanisms driven by a spring clock have only one rate of speed which may be either 1-day or 7-day.

In the later types a dial-type register within the meter is used to add up the number of received impulses. This register is connected to the armature of the operating electromagnet, and through a pawl and ratchet on the register each driving impulse is integrated by the register. The difference between successive readings, when multiplied by the proper constant, will give kilowatthours to be compared with corresponding kilowatthours as registered by the watthour meter. Thus, a check on the operation of the contact device as well as the

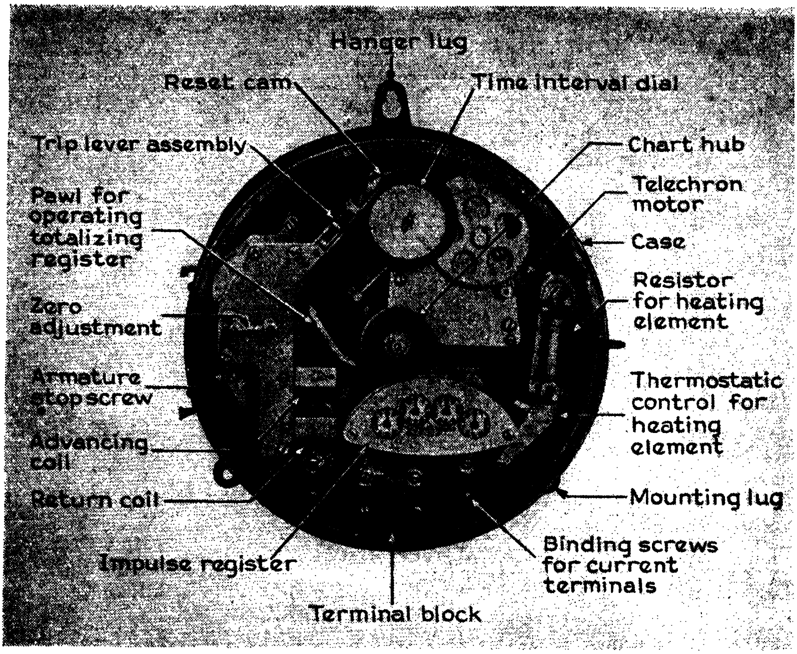


Fig. 14-33. Type G-9 Graphic Demand Meter, internal view

recording mechanism of the demand meter is provided.

Description of Various Types—Meters similar to those of the Type G series, but arranged for back connections, constitute the GS series. With the exception of the case, terminals and mounting facilities, corresponding meters of both series are the same.

Meters similar to those of the Type G series, but arranged so that they are portable, through the addition of a carrying handle and leveling feet, constitute the Type GP series.

Type G-8 Demand Meters

This demand meter supersedes previous types and is the first of the meters of the Type G series to be equipped with the electromagnetic return coil controlled by one side of the contact device. It is also equipped with an impulse-counter register. Another modification is an improved heating unit.

Type G-9 Demand Meters

This demand meter supersedes the Type G-8 and includes a further improvement of the heating element as well as other improvements affecting interchangeability of parts. See Fig. 14-32, 14-33, 14-34.

Type GS-12 Demand Meters

This demand meter is similar to the Type G-9 except that it is equipped with a narrow flange for flush-mounting.

Design Modifications — Meters equipped with a Telechron motor driving mechanism are designated by the form letter W. Those equipped with a spring-driven clock mechanism are designated by the form letter C.

Meters in which the armature of the operating magnet is returned to its de-energized position by a permanently excited electromagnet are designated by the form letter E, while those of the spring-return types are designated by the form letter S.

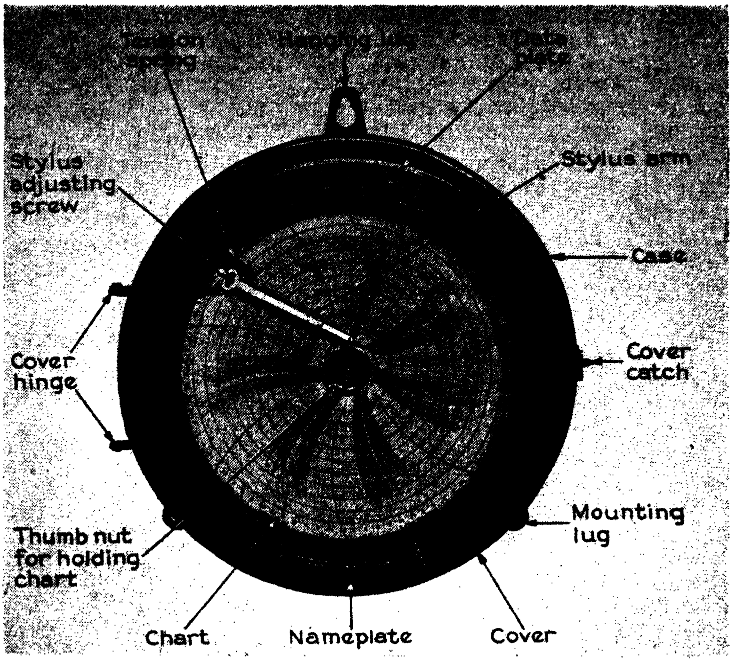


Fig. 14-34. Type G-9 Graphic Demand Meter

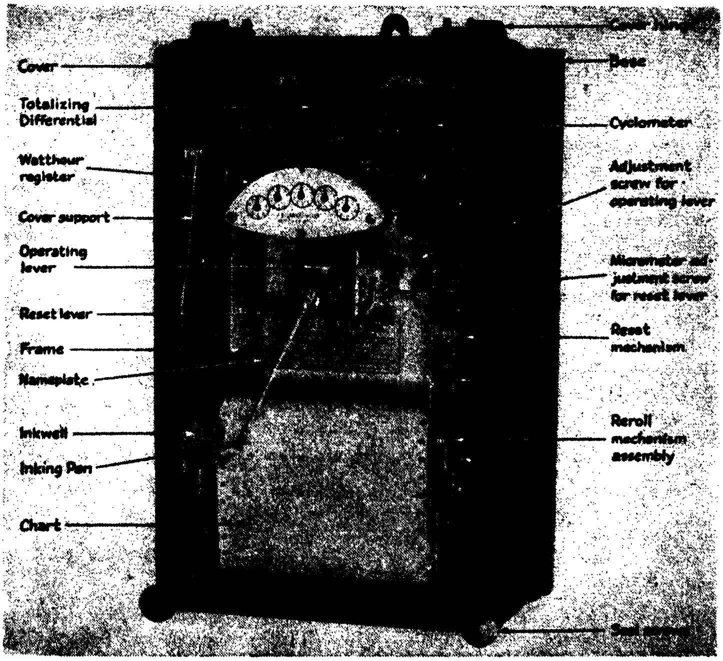


Fig. 14-35. Type BR-1 Recording Demand Meter

Meters in which the armature of the operating electromagnet is returned by electrical impulses from one side of the contact device in the watthour meter are for use with three-wire contact devices.

This is the standard construction and is not identified by form letter.

When arranged to totalize the demand of two meter circuits, the meters are equipped with a two-section advancing coil and are geared so that either 104 or 208 impulses are required to advance the stylus over the full chart range. These meters always use either a spring or a permanently excited electromagnet for returning the armature of the operating electromagnet to its de-energized position. This totalizing or duplexing feature, when the gearing is such that 104 impulses are required to advance the stylus over the full scale, is designated by the form letter D; when the gearing is such that 208 impulses are required to advance the stylus over the full scale, the form designation is D-2.

Meters equipped with alarm contacts to operate a signal when the demand reaches some predetermined value are designated by the form letter A.

The design of certain forms of these meters is modified so that the records produced are inverted, in which case the zero is at the outer edge of the chart rather than at the center. This modification is designated by the form letter I.

The use of a steel stylus is standard, but an inking pen for recording the demand is optional. When equipped with an inking pen the meters are designated by the form letter P.

The Form W design, with the Telechron motor drive, may be modified so that two chart speeds are obtained by adjusting a gear shift lever. When this feature is included the meters are designated by the form letters WX.

Charts for Meters

The charts are calibrated around the outer edge to indicate both the day and the hour of the day. Standard charts are calibrated radially to indicate advancing impulses delivered to the meter. These charts have 52 main divisions, marked from 0 to 104 for Form D meters, or 0 to 208 for Form D-2 duplex meters. Therefore, the readings must be multiplied by a constant for converting to kilowatts of demand.

Wax-Coated Charts. Chart Finish "A"—Standard charts for meters employing a steel stylus are of black paper with a thin coating of especially prepared wax on the surface. This gives the appearance of an almost white face. These charts are for use only when the operating temperature does not exceed 100 F. The graduations are printed on the wax in orange-colored ink. The stylus, in tracing a record in the wax, exposes the black background.

Plain Charts for Ink Records. Chart Finish "B" — Charts for meters equipped with an inking pen are of plain white paper. These charts may be used where the temperature is likely to exceed 100 F.

Carbon Charts. Chart Finish "C"—A carbon chart consisting of a plain white paper chart in combination with a carbon paper is used on meters with a steel stylus. These charts should not be used where the temperature exceeds 120 F.

Types BR-1 and BR-2 Demand Meters

These meters combine in one device a two-circuit a-c contact-operated totalizing relay and a strip-chart recording demand meter, block-interval type, of the same general design as the DG demand meter. It is for use with two watthour meters equipped with three-wire contact devices to obtain the total simultaneous demand of two metered circuits. The Type BR-2 is an identical device except for semiflush mounting. Fig. 14-35 shows the Type BR-1 demand meter.

DEMAND-LIMITING METERS

Types GM-10 and GMS-11

These meters are for use in connection with watthour meters equipped with contact devices to assist in keeping the maximum demand at the lowest practical level. This is accomplished by having a set of alarm contacts in the demand meter arranged to operate if the integrated load has exceeded a predetermined value for any elapsed part of the demand interval. See Fig. 14-36.

CONTACT-OPERATED, PRINTING DEMAND METERS

These meters are for use with a watthour meter equipped with a three-wire contact device, and a contact-making clock which determines the demand interval. They record the kilowatt demand on a tape together with the time of the day at which the separate demands occurred. The printed figures on the tape, when multiplied by a constant, give the demand in kilowatts. The record is printed from type figures carried on type wheels electromagnetically advanced by impulses from the watthour meter contacts. In the PD series, which supersedes the P series, the type wheels are reset to zero at the end of each demand interval by the contact-making clock which controls both the printing and release mechanism of the demand meter.

PD Series

Schematic diagram Fig. 14-37 illustrates the operating principle. As successive electrical impulses are made by the contact device installed on the watthour meter, the electrical circuits, through the two coils, are closed alternately. As the respective iron cores are drawn into these coils, they operate the walking beams and ratchet pawls and advance the type wheel one unit for each closing of the electrical circuit. A link connection with the impulse counter causes a registration of the number of times this mechanism is actuated.

At the end of each demand interval the contact-making clock closes the electrical circuit through the printing coil and the reset coil. The energizing of the printing coil causes the printing platen to press the paper record tape, with the carbon tape interposed, against the type numerals on the face of the type wheels and thus secures the printed record of the stage to which the type wheels are advanced during the completed demand interval. After the printing mechanism has functioned, the reset coil operates a system of levers which disengages the advancing pawls, latching them in this

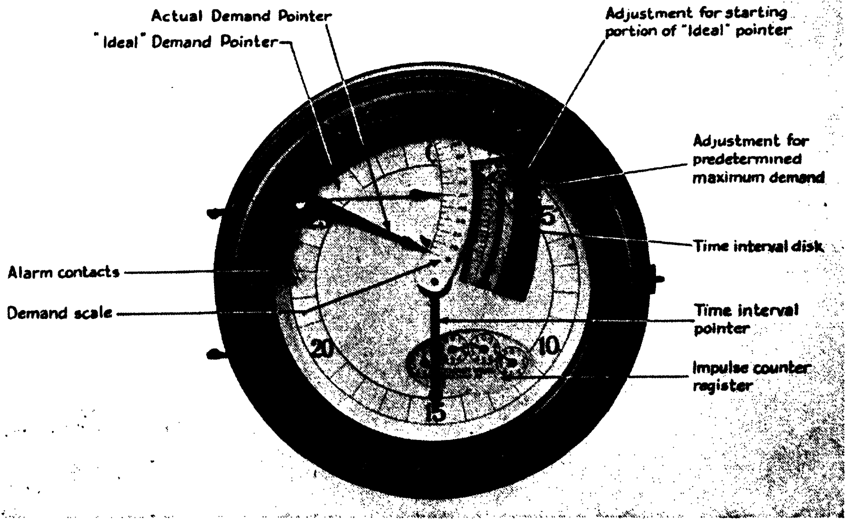


Fig. 14-36. Type GM-10 Demand Limiting Meter

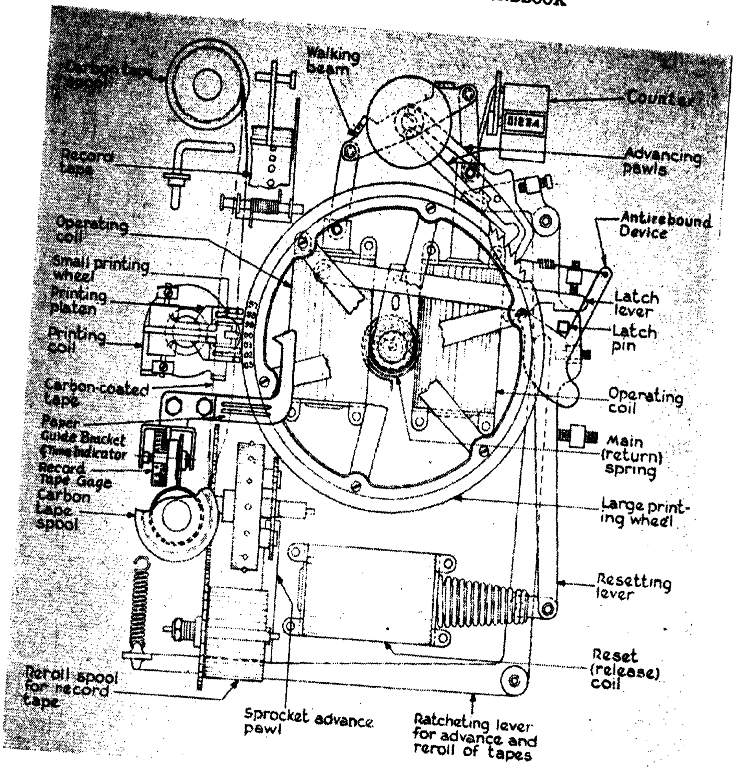


Fig. 14-37. Type PD-5 Printing Demand Meter—Schematic Diagram

position until the spring has returned the type wheels to the zero position. A lever at this time advances the carbon tape and the record tape. When the type wheel reaches its zero position, a stud on it disengages the latch which has held the advancing pawls free of the ratchet on the type wheel.

The return of the type wheels to zero leaves the maximum demand indicator at the most advanced position to which the type wheels have carried it during any past demand interval. It must be manually reset after records are made of its readings.

Each demand meter has two indicators and a mechanically operated impulse counter. One indicator shows at all times the stage of advance of the type wheels from the zero position, and therefore indicates what the printed record would be, should the printing mechanism function at that instant. The other indicator shows the maximum advance of the type wheels during any interval since the indicator was previously reset manually to its zero position. This indicator, therefore, gives an indication of the maximum demand. The impulse counter shows directly the number of times the contact device on the watthour meter has closed the electrical circuit to the demand registering mechanism of the demand meter. Its indications can be used in making a check on the operation of the demand registering mechanism and the function of the contact device used on the watthour meters.

Meters of the Type PD series are either for alternating-current or direct-current service, depending upon the rating. For 230-volt direct-current service, an external single-tube resistor is required in the common line to the three-wire contact device. For service above 240 volts direct-current, a battery-operated (18 volts) meter is available. For alternating-current service of 460 or 575 volts, a small transformer may be used for the operation of the standard 115-volt demand meter.

Description of Types—Meters of the PD series, other than those for semiflush mounting, are arranged for either front or back connections. Only three types of meters, for use with external contact-making clocks, have been manufactured in this series: the PD was superseded by the PD-5, and PD-6 is for semiflush mounting. The three differ only in minor details. See Fig. 14-38.

Type PD-7 Demand Meter

This demand meter is like the PD-5 except that an interval-timing mechanism of the Telechron synchronous motor type is incorporated in the meter. It is located in the back of the meter but can be readily inspected. An interval dial and a time-resetting knob are provided, located at the front of the meter.

Operating Principle—Interval timing is accomplished by means of *on* and *off* riders which ride on two cams. One cam rotates one revolution per minute, and the other rotates one revolution during the rated interval. Once every interval, two teeth of the cams are in a position which permits the contact to close momentarily the electrical circuits through the printing and release coils of the meter, as with a conventional contact-making clock. See Fig. 14-39. The contacts have sufficient capacity to carry the burden of the printing and reset coils in the PD-7 meter and one additional PD-5 meter.

Design Modifications—Meters of the Type PD series may be equipped with an alarm contact device and also with a heating element controlled by a thermostat.

The alarm contacts are for operating a signal when the demand reaches a predetermined value and are designated by the form letter A.

The heating element (80 watts) is for maintaining the temperature inside the case at the minimum value for

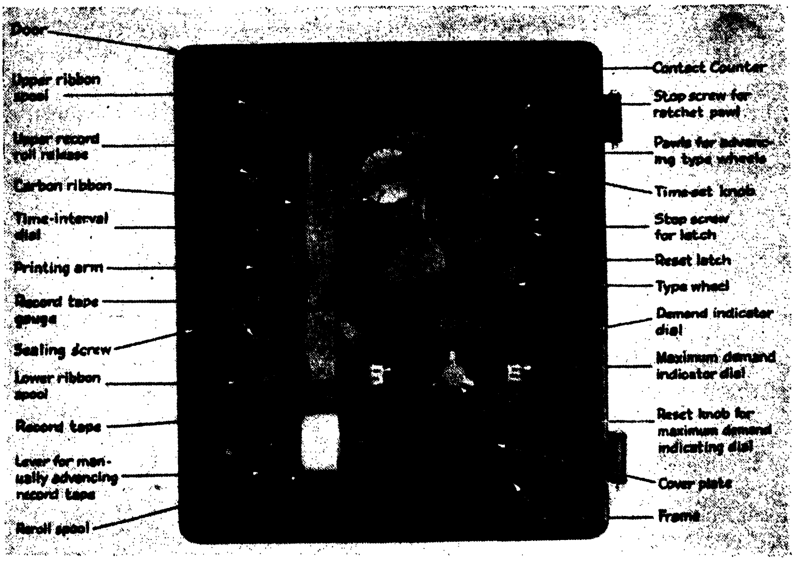


Fig. 14-38. Type PD-7 Printing Demand Meter

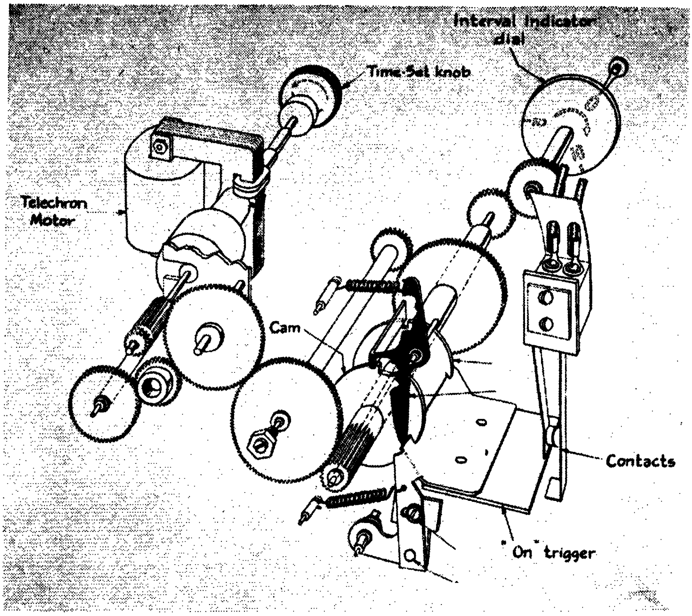


Fig. 14-39. Type PD-7 Demand Meter Timing Mechanism—Schematic Diagram

satisfactory operation; with the heating element the meter is suitable for use in temperatures down to minus 20 F.

CONTACT-MAKING CLOCKS

Type C and CS Series

These contact-making clocks are designed to govern the demand interval of printing types of demand meters.

Operating Principle—In addition to the usual time-indicating dial and hands, the clock is equipped with a two-wire contact device which is momentarily closed after a predetermined elapsed time. This elapsed time is determined by the chosen demand interval of the demand meter with which the clock is to be used. The contacts are closed through the action of an escapement mechanism which is actuated by the clock movement and which permits only one closure of short duration at the end of each demand interval.

The clock may have a Telechron motor-driven movement, a spring-driven, key-wound, eight-day movement, or a spring-driven, motor-wound movement with a twelve-hour carry-over.

Clocks may be equipped with a 25-watt heating element for maintaining the temperature inside the case at a minimum value for satisfactory operation where the ambient temperature may go below 0 F.

Contact Rating—The contacts in the clock are of sufficient capacity to operate two demand meters, except for the 18-volt capacity of which only one can be operated from one clock. Where more demand meters are involved, a relay should be used.

Type Designation in C and CS Series—The Type CS in each case is the back-connected form of the Type C.

Types CS-8 and C-8

These clocks are for alternating-current service, have Telechron motor-driven units, and are enclosed in a glass cover with a cast-iron base.

Types CS-9 and C-9

These clocks are equipped with spring-driven, eight-day movements and are enclosed the same as the Types C-8 and CS-8.

Type C-11

This clock supersedes the Types C-8 and CS-8. The base is molded and is arranged for either front connections or back connections. This clock movement differs from those used in the Types C-8 and CS-8 in that the gearing is re-arranged to provide greater accuracy.

Type C-12

This clock supersedes the Types C-9 and CS-9. The movement is similar to those used in the Types C-9 and CS-9, but has minor changes in the internal mechanism which insure greater interval accuracy. The base and the cover are the same as used for Type C-11 clocks.

Type C-13

This clock is equipped with a spring-driven, motor-wound movement either for alternating-current or direct-current service depending upon the motor and gearing used. The base and the cover are the same as for the Type C-12.

Type C-14

This clock is for alternating-current service and has a Telechron motor-driven unit. The base and the cover are the same as used for Type C-12 clocks. See Fig. 14-40.

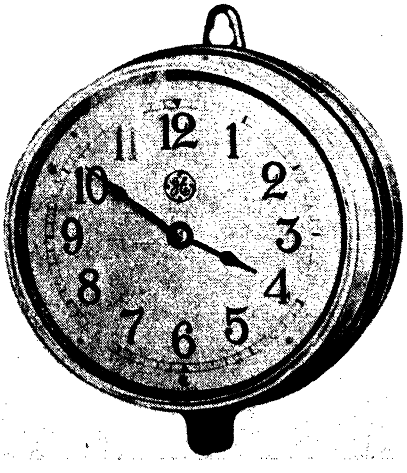


Fig. 14-40. Type C-14 Contact-making Clock

Type C-15

This clock is similar to Type C-13 except that it is for semiflush mounting. The case is of drawn steel, rectangular in shape, and has a narrow flange.

Type C-16

This clock is similar to the Type C-14 except that it is for semiflush mounting. The case is of drawn steel, rectangular in shape, and has a narrow flange.

Type C-17

This clock is similar to the Type C-12 except that it is for semiflush mounting. The case is of drawn steel, rectangular in shape, and has a narrow flange.

DEMAND METER RELAY SWITCHES

Type R Series

Each relay of the Type R series is designed to increase the capacity of the contacts in the contact-making clock, where one clock is to simultaneously control the demand interval of more than one meter rated at 18 volts, or more than two meters rated 115 or 230 volts of the Type PD series. Each relay consists essentially of a magnetic switch, or contactor, controlled by the contact-making clock. The base and cover for the R-6 are the same as used in the Type C-12 clock. The case for the R-7 is the same as used in the Type C-15 clock.

CONTACT DEVICES

Types D-5, D-12 and D-13

These contact devices are for use on watthour meters to advance the registering mechanism of contact-operated demand meters or totalizing relays. They function so that the impulses are transmitted at a rate proportional to the load on the watthour meter. See Fig. 14-41.

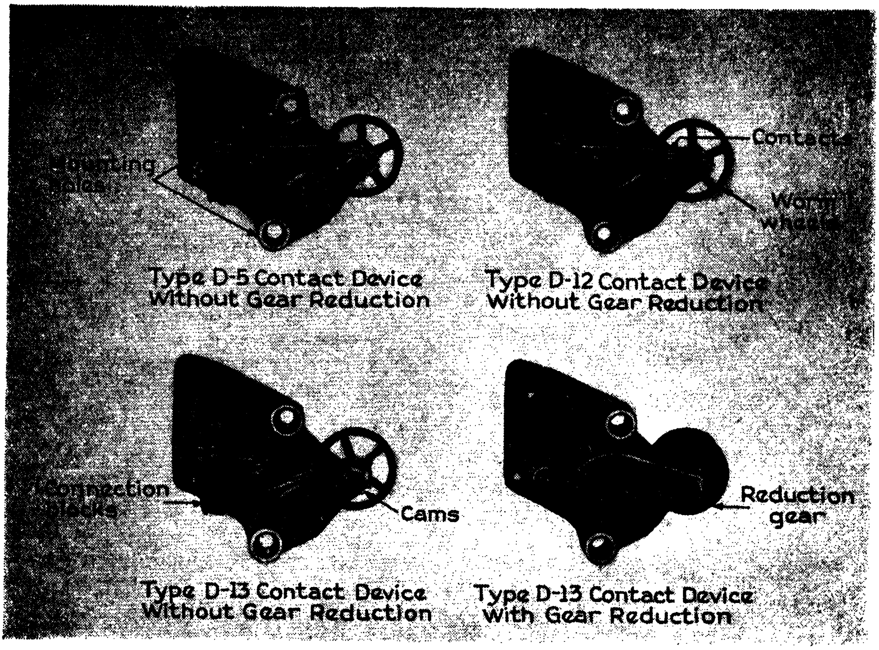

Mounting holes
Contacts
Worm wheels
Type D-5 Contact Device Without Gear Reduction
Type D-12 Contact Device Without Gear Reduction
Connection blocks
Cams
Reduction gear
Type D-13 Contact Device Without Gear Reduction
Type D-13 Contact Device With Gear Reduction

Fig. 14-41. Types D-5, D-12 and D-13 Contact Devices

The Type D-12 contact device operates on the two-wire or single-circuit principle. Both the Types D-5 and D-13 contact devices operate on the three-wire or double-circuit principle. Type D-5 contact devices differ from the Type D-13 in that they have not only quick-make action but also quick-break action. The Type D-5 and Type D-13 contact devices can be used interchangeably for most applications. However, certain applications require the Type D-5 contact devices.

Contact devices used with alternating-current watthour meters and also with the direct-current mercury meter, Type HS-11, are driven from a second worm on the watthour meter shaft.

Contact devices for use with all direct-current meters, with the exception of the Type HS-11, are driven from a single-pitch worm on the shaft of the rotating element. The worm wheel and bracket of the register are replaced by a special worm wheel and bracket which support the contact device. The contact cams are driven from a gear on the worm-wheel shaft.

The Types D-5, D-12, and D-13 contact devices are equipped with a ratchet device which serves to protect the brushes and other parts from mechanical injury in case the direction of rotation of the watthour meter shaft should be reversed.

On contact devices of recent manufacture, the type of contact device, points on cams, and revolutions of worm-wheel shaft to revolutions of cam shaft are stamped on the contact-device-mounting plate. For contact devices without intermediate gearing between worm-wheel shaft and cam shaft this ratio is omitted. For instance, "D-13-5" indicates a Type D-13 contact device having 5-point cams. For contact devices with the intermediate gearing, the marking includes the ratio. For instance, in "D-12-5" and "1-3," the "1-3" marking indicates 1 revolution of the worm-wheel shaft is equal to 3 revolutions of the cam shaft.

Where contact devices are driven from an extra worm on the watthour meter shaft, the pitch of this worm is indicated by the number of rings or grooves cut on the shaft next to the worm. A single-pitch worm therefore has one ring, a double-pitch two rings, and a quadruple-pitch four rings.

KILOWATT CONSTANT

When demand meters are equipped with arbitrarily calibrated charts, scales or record tapes (non-direct reading), and are operated by impulses from contact devices in watthour meters, it is necessary to multiply the demand meter readings by a kilowatt constant to convert such readings to kilowatts of demand.

The value of the kilowatt constant to be used depends upon the type of watthour meter, its rating, and upon the type of the contact device, number of points on the cams, ratio of revolutions of worm wheel to cam shaft, worm pitch, demand interval and upon the type of demand meter. All contact-operated demand meters are divided into two groups. Group 1 comprises those meters belonging to the Types M and G series. For this group, when the D-13 or D-5 contact device is used, only one-half of the total number of impulses advance the indicating mechanism of the demand meter, the other half being used to restore the advancing mechanism to its initial position. When the D-12 contact device is used on meters with either spring return or electromagnetic return, the total number of impulses advance the indicating mechanism of the demand meter.

The meters belonging to Group 2 are of the Type PD series. These meters can be used only with the 3-wire or double-circuit contact device such as the Type D-13 or D-5 contact device. They differ from Group 1 in that each impulse serves to advance the registering mechanism. This accounts for the factor of ½ in the equation for determining the kilowatt constant for meters in Group 2.

The basic equation for computing the kilowatt constant is as follows:

$$\text{Kw constant} = \frac{R \times K_h}{1000 \times I}$$

Where

R = Revolutions of meter disk for each contact that advances the demand meter.

K_h = Watthour constant.

I = Demand interval expressed in hours.

In applying this equation it should be noted that for the Group 1 demand meters used with D-13 or D-5 contact devices, only one half of the total impulses advance the demand meter.

When instrument transformers are used with primary rated meters, this formula applies by using the primary value of K_h.

When instrument transformers are used with secondary rated meters, the ratio of the instrument transformers must be considered. The equation is then as follows:

$$\text{Kw constant} = \frac{R \times K_h}{1000 \times I} \times PT_r \times CT_r$$

Where

PT_r = Ratio of potential transformers.

CT_r = Ratio of current transformers.

Equations, applicable to General Electric contact type demand meters, which consider all constants and mechanisms, to be used for computing the kilowatt constant are as follows:

For demand meters, Group 1:

$$\text{Kw constant} = \frac{K_h}{1000 \times N \times I} \times \frac{\text{Teeth of w. w.}}{\text{Shaft worm pitch}} \times \frac{\text{Rev. of w. w.}}{\text{Rev. of cam}}$$

For demand meters, Group 2:

$$\text{Kw constant} = \frac{1}{2} \times \frac{K_h}{1000 \times N \times I} \times \frac{\text{Teeth of w. w.}}{\text{Shaft worm pitch}} \times \frac{\text{Rev. of w. w.}}{\text{Rev. of cam}}$$

In both equations:

K_h = Watthour constant.
N = Number of points per cam.
I = Demand interval expressed in hours.

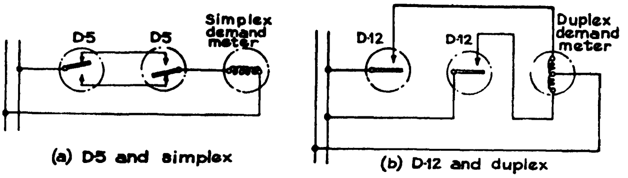
Teeth of w. w. = 100 for all General Electric meters, except 50 for 2-element V-series meters.

NOTE: The last term in both equations is the number of revolutions of the contact-device worm wheel for one revolution of the cams. The relation need be considered only when contact devices with intermediate gearing between worm-wheel shaft and cam shaft are used, since for contact devices without intermediate gearing the value of this term is 1.

Advancing Impulses—It is often desirable to know the number of advancing impulses per demand interval for a certain load on the watthour meter. This information is of particular interest in determining the overload rating of the demand meter operated from the contact device, and also in checking the demand for any known load on the watthour meter. The following equation can be used for calculating the number of advancing impulses for all contact-operated demand meters.

For demand meters, Groups 1 and 2:

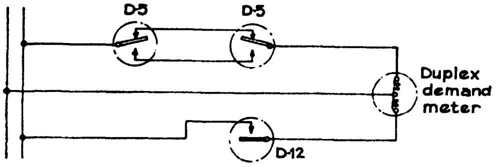
$$\text{Adv. impulses} = \frac{\text{Kilowatt load}}{\text{Kilowatt constant}}$$



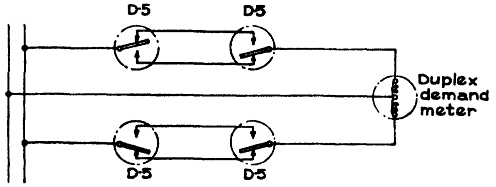
(a) D-5 and simplex

(b) D-12 and duplex

Totalizing two circuits



Totalizing three circuits



Totalizing four circuits

Fig. 14.-42. Type D-5 Contact Device—Schematic Diagrams for Totalization of 2, 3 or 4 Circuits

Duplexing—The kilowatt constant for any duplexing installation must be of the same value for both watthour meters, and the number of advancing impulses delivered to the demand meter, considering both circuits, should range from 150 to 170 per interval (assuming 200 advancing impulses for full-scale deflection) when both watthour meters are operating under normal maximum load. If the number of advancing impulses are within these limits, the demand meter will usually have ample range and a satisfactory reading can be obtained for light loads.

The method of calculating the kilowatt constant for duplex installations is the same as that where there is but one circuit to consider.

The number of advancing impulses for a duplexing installation is the sum of the advancing impulses received from the two watthour meters. The method to be used in obtaining the number of advancing impulses per interval per watthour meter is the same as for the single-circuit installation.

Duplexing with Type D-5 Contact Devices—Since there is practically no time delay between the opening of one side of the contact device and the closing of the other, the Type D-5 contact device may be used to totalize the demand of two circuits on a simplex demand meter, or four circuits on a duplex demand meter.

When used for totalizing purposes, however, the Type D-5 contact device functions to open or close a 2-wire circuit. The demand meter must, therefore, be of a construction suitable for 2-wire operation.

The methods of connection for totalizing demand of 2, 3 and 4 circuits are shown in Fig. 14-42. In each case a change from one side to the other in one contact device will either close or open the circuit to the operating coil of the meter. A complete cycle of operation of each contact device from one side to the other and back again will, therefore, produce one impulse, like a D-12 contact device.

INTERMEDIATE RELAYS

Types S-1 and S-2

These devices are primarily for use where one three-wire contact device on a watthour meter is to operate simultaneously several contact-operated demand meters or totalizing relays. The relay functions to relieve the contact device in the watthour meter from the excessive burden which would otherwise be imposed on it. The Type S-1 intermediate relay is for switchboard mounting, and the Type S-2 is for semiflush mounting.

TOTALIZING RELAYS

Type DT Series

Each totalizing relay of the Type DT series is for use with a contact-operated demand meter and several watthour meters, each equipped with a three-wire contact device, to obtain the total simultaneous demand of a number of metered circuits. It functions to receive and totalize demand impulses from the contact devices in the watthour meters and to transmit impulses to the demand meter or other totalizing relay. These relays are constructed for 2, 4, 6, or 8 circuits.

Operating Principle—Each circuit of the relay is connected to the three-wire contact device in the watthour meter with which it is to operate. As successive electrical impulses are produced by this contact device, the electrical circuits of the two operating solenoids are alternately closed. This causes the plungers to be drawn into their respective solenoids and, through an arrangement of two pawls, a ratchet, differential gearing and a spiral spring, to operate a contact device within the totalizing relay. These parts are designed and arranged such that one impulse will be transmitted by the relay for a definite number of impulses received by it. See Fig. 14-43.

The impulses transmitted by the relay to the demand meter or other totalizing relay are spaced apart in time, although several impulses may be received simultaneously by the relay. This time spacing is provided to

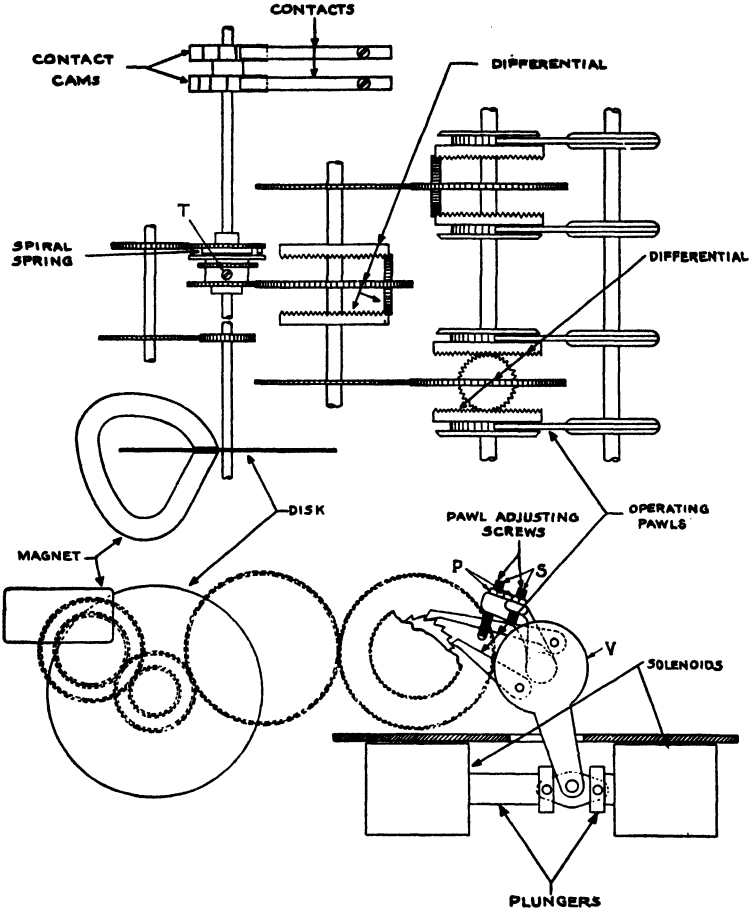


Fig. 14-43. Type DT-3 Multiple-circuit Totalizing Relay—Schematic Diagram for 4-circuit Construction

allow the connected demand meter sufficient time to respond to each impulse. It is obtained through the spiral spring which serves as a coupling between the differential gearing and contact cams, together with a damping disk magnet which limits the speed at which the contacts operate.

Description of Types—Relays of the Type DT series are primarily for back connections.

Each circuit of the relay except DT-1 is equipped with a cyclometer which registers the number of impulses received. The shaft which drives the outgoing contact device also has a cyclometer. Thus it is possible to maintain a very close check on the performance of the entire equipment, as well as each part of the equipment, back to the individual watthour meters.

Type DT-1

These totalizing relays have been made in 2-, 4-, 6-, and 8-circuit constructions for 115 or 230 volts, a-c or d-c operation.

Type DT-2

These totalizing relays supersede the Type DT-1 relays and differ mainly in that stops are added to prevent the advancing pawls from over-traveling.

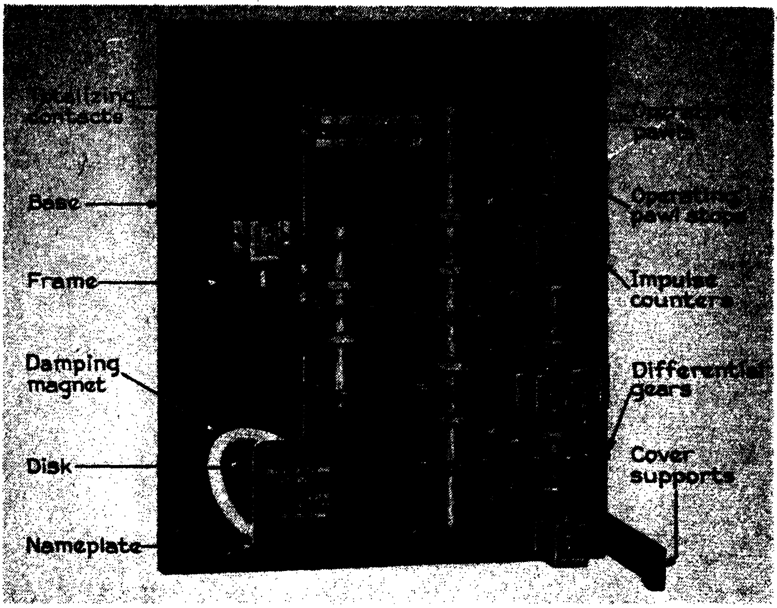


Fig. 14-44. Type DT-3 Multiple-circuit Totalizing Relay—Front View of 6-circuit Construction, covers removed

Cyclometer counters are also added for all incoming circuits as well as the outgoing circuit.

Type DT-3

These totalizing relays supersede earlier types of relays. Several design improvements have been made. See Fig. 14-44.

TOTALIZERS

Type MD-1-D2

When this device is equipped with an outgoing contact device, it functions as a totalizing relay to totalize the demand of 2, 3, or 4 circuits. If it is equipped with a demand register (Types M-20, M-21, or M-31) it serves as a totalizing indicating demand meter for totalization of 2, 3, or 4 circuits.

Operating Principle—The MD-1-D2 totalizer is fundamentally a 4-circuit device, operated on the two-wire principle from two-wire Type D-12 contact devices.

For each circuit there is one duplex operating coil with an associated armature and advancing pawl, operating on a ratchet wheel. The motions of the two ratchet wheels are totalized on a summation or differential mechanism. See Fig. 14-45.

When the totalizer is equipped with a 2-wire outgoing contact device, the standard contact ratio is 4/1, that is, four incoming impulses will produce one outgoing impulse.

In the case of the 3-wire outgoing contact device, the standard contact ratio is 2/1 and corresponds to the 4/1 ratio for the 2-wire outgoing contact device.

Construction — The mechanism is mounted on a supporting grid and is housed in a die-cast aluminum base provided with a cover. The terminal chamber is suitable for either conduit or meter trim connections. Impedors are provided to improve operation of the contact devices in the watthour meters. The totalizer is equipped with two cyclometer impulse counters, one for each operating coil.

Forms — Several constructions have been built and identified by form let-

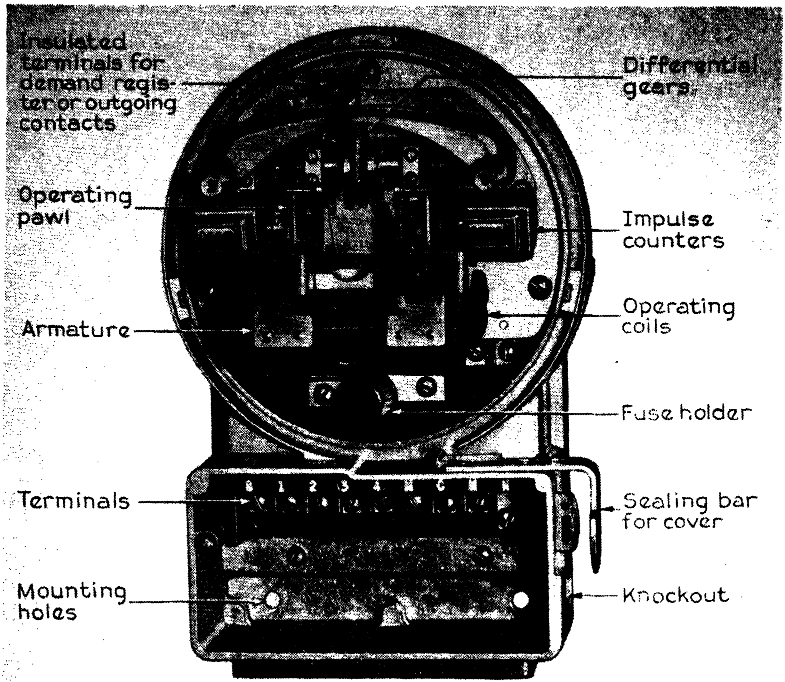


Fig. 14-45. Type MD-1-D2 Two-element Totalizer, covers removed

ters to signify the type of demand register or outgoing contact device the totalizer is equipped with.

Form M-20—With Type M-20 demand register
Form M-21—With Type M-21 demand register
Form M-31—With Type M-31 demand register
Form D-6—With 2-wire outgoing contact device
Form D-7—With 3-wire outgoing contact device

With the exception of the cover, registers, and outgoing contact devices, the forms are alike.

Type MD-3

These totalizers may be used either as a combination of a 2-circuit totalizing relay and an indicating demand meter, or as a 2-circuit totalizing relay.

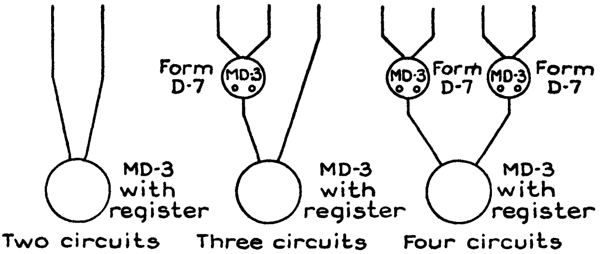
In the first construction the device is used to totalize and give the indicated maximum totalized demand of two metered circuits. It is then equipped with a demand register, either Type M-20, M-21, or M-31.

In the second construction, the demand register is replaced by an outgoing contact device. It is then used with any of the standard contact-operated types of demand meters, such as M-16, G-9, or PD-5, or other totalizers or totalizing relays. Schematically this is shown in Fig. 14-46.

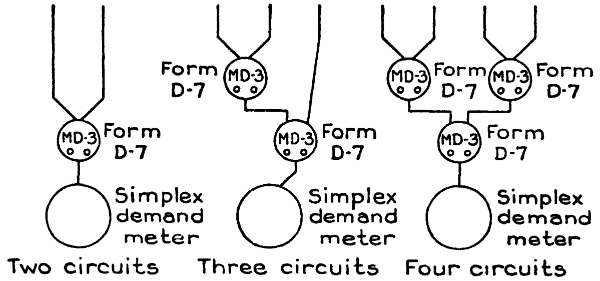
The totalizers are for a-c operation only, as they are actuated by Telechron motors.

Operating Principle—Instead of the conventional coil, plunger and ratchet arrangement, the totalizer employs for each circuit a Telechron motor controlled by 3-wire contacts, in principle like the Type D-5 contact device.

A simplified diagram of connections and a schematic diagram of operation are shown in Fig. 14-47. The mechanism proper for Type MD-3 is illustrated in Fig. 14-48.



INDICATED TOTALIZED DEMAND



RECORDED TOTALIZED DEMAND

Fig. 14-46. Type MD-3 Two-circuit A-C Totalizer—Line Diagrams for Totalization of 2, 3 or 4 circuits

The two watthour meters are equipped with 3-wire contact devices, Type D-5 or D-13. These are connected to the 3-wire contacts A and B in the totalizer, and from there through two Telechron motors.

In the schematic diagram the Telechron motors are left out and only the worms C and D on the motor shafts are shown. Worm C is in mesh with gear E, and gears E and H together with the cams, on which brushes A rest, are mechanically a unit. Rotations of worms C and D are totalized by a differential or summation gearing to ring gear G.

When, for example, the contact device in the lower watthour meter changes to the other side, the Telechron motor becomes energized, and worm D drives the cams for contacts B until they open that side and close on the other side. Simultaneously the motion is transferred to ring gear G.

Ring gear G, therefore, is rotated in direct proportion to the total number of impulses from both watthour meters. A demand register, either Type M-20, M-21, or M-31, may be meshed with it and will then indicate the totalized maximum demand. Likewise a 3-wire outgoing contact device may be meshed with ring gear G, in which case the totalizer will function as a 2-circuit totalizing relay.

While only one coil is used per circuit in the totalizer, the scheme of operation incorporates practically all of the advantages and safety features of the 3-wire contact device principle.

The Telechron motors are Type B-9, 1 rps. The worm on the motor pinion has a quadruple pitch and meshes with a 36-tooth gear E or F. Since the cams have 6 points, the cam shaft must make 1/12th of a revolution to record one impulse. This corresponds to 9/12 or 3/4 of a revolution of the motor pinion. Thus approximately 3/4 of a second is required to record one impulse.

Every impulse produced by the contact devices in the watthour meters is advancing, that is, each will cause the ring gear G to rotate 1/24th of a revolution. If the points on the cams in the contact devices in the watthour meters are 6, as for the cams in the

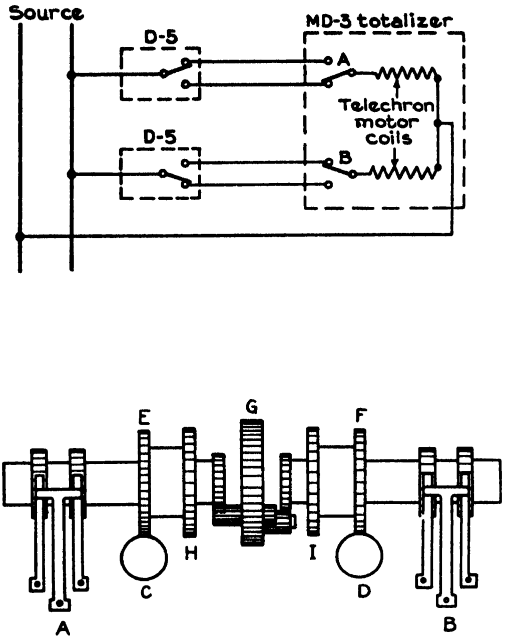


Fig. 14-47. Type MD-3 Two-circuit A-C Totalizer—Schematic Diagrams of Connections and Operation

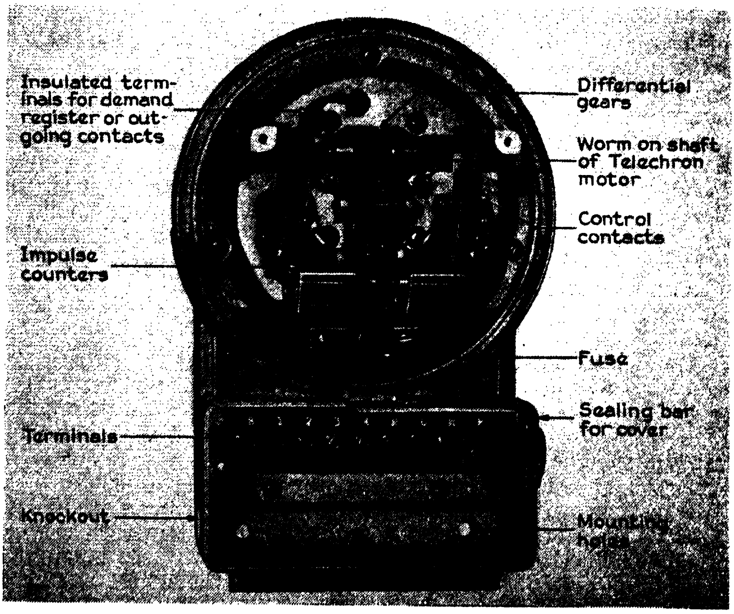


Fig. 14-48. Type MD-3 Two-circuit A-C Totalizer, covers removed

totalizer, gears H and I will make the same revolutions as the cams in the contact devices in the watthour meters.

The summation mechanism has the fundamental gear reduction of 2/1, so with gear I standing still, ring gear G will rotate at half the speed of gear H.

The contacts in the totalizer are like the Type D-5 contact devices. They are 2-position contacts, that is, with one side open the other side is closed, and vice versa.

When equipped with an outgoing contact device, the standard contact ratio is 2/1; that is, two incoming impulses will produce one outgoing impulse. A contact ratio of 1/1 is not recommended when the outgoing contact device is connected to another MD-3 totalizer, since the duration of an outgoing impulse may then be too short to allow the connected MD-3 totalizer time to record the impulse properly.

Forms—The totalizers have been built in several constructions and identified by form letters to signify the type of demand register or outgoing contact device they are equipped with.

Form M-20—With Type M-20 demand register
Form M-21—With Type M-21 demand register
Form M-31—With Type M-31 demand register
Form D-6—With 2-wire outgoing contact device
Form D-7—With 3-wire outgoing contact device

The Type MD-3 uses the same base as the MD-1-D2 totalizer.

THERMAL DEMAND METERS

These devices are complete demand meters for use separately with a-c watthour meters. They are of the lagged type, responding in accordance with the logarithmic or heating law. The maximum kilowatt demand is indicated by a friction pointer and scale.

Type HI-1-A

The Type HI-1-A thermal watt demand meter is for use on single-phase

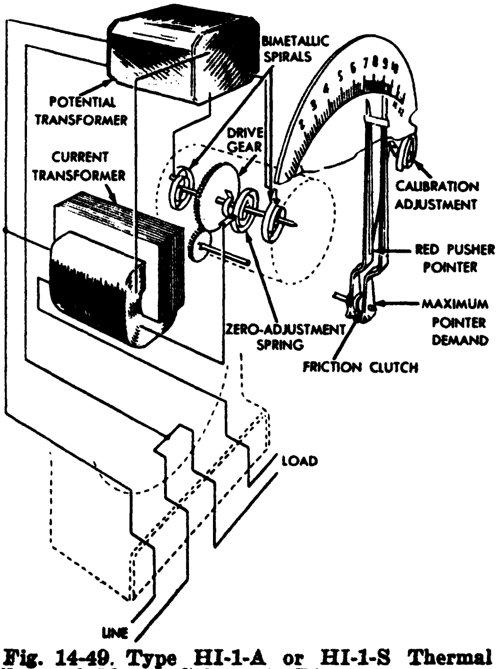


Fig. 14-49. Type HI-1-A or HI-1-S Thermal Demand Meter—Schematic Diagram

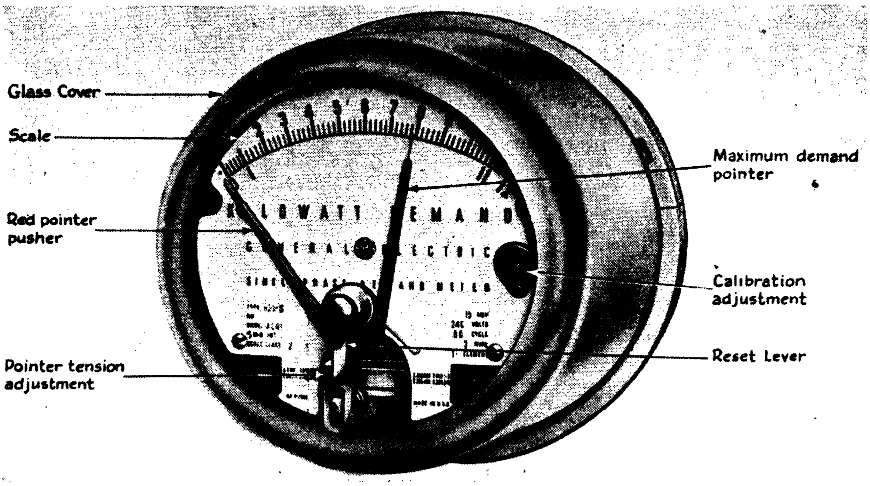


Fig. 14-50. Type HI-1-S Thermal Demand Meter

alternating-current circuits and measures the demand in kilowatts. It is furnished either for 2-wire or 3-wire service.

The principle of operation is that of the conventional thermal watt demand meter. The two bimetallic spirals, connected to the secondaries of a potential and a current transformer, act as conductors as well as heaters. See Fig. 14-49. The thermal element acts therefore on the direct-heat principle.

The meter is of the same general mechanical construction as the I-30-A watthour meter and is similar in appearance.

Type HI-1-S

This meter is similar to the Type HI-1-A except that it is of the detachable or socket type. See Fig. 14-50.

COMBINATION WATTHOUR THERMAL DEMAND METERS

Type IHM-1-A

The Type IHM-1-A combination watthour thermal demand meter is for use on single-phase alternating-current circuits and measures the demand in kilowatts and the energy in kilowatthours. It is furnished either for 2-wire or 3-wire service.

The watthour meter element is similar to that of the Type I-50 watthour meter except that the moving element and bearings are of the conventional ball-bearing type.

The watt demand element is similar to that of the Type HI-1 except that the physical arrangements of the parts permit it to be assembled with the watthour element as a compact unit.

The meter is of the same general mechanical construction as the I-30-A watthour meter and is similar in appearance.

Type IHM-1-S

This meter is similar to the Type IHM-1-A except that it is of the detachable or socket type.

COMBINATION WATTHOUR THERMAL KILOVOLT-AMPERE METER

Type IHE-1-A

The Type IHE-1-A combination watthour thermal kilovolt-ampere meter is for use on single-phase alternating-current circuits and measures the demand in kilovolt-amperes and the energy in kilowatthours. It is furnished either for 2-wire or 3-wire service.

The watthour meter element is similar to that of the Type IHM-1 combination watthour thermal demand meter.

The kilovolt-ampere demand element is similar to that of the IHM-1. A resistance valve, controlled by the line voltage, is introduced into one of the bimetallic spirals in such a manner as to cause the device to measure kilovolt-ampere demand.

The meter is of the same mechanical construction as the IHM-1-A combination watthour thermal demand meter and is similar in appearance.

Type IHE-1-S

This meter is similar to the Type IHE-1-A except that it is of the detachable or socket type.

DIRECTIONS FOR USE OF TABLES

General data on the various types of watthour meters are given in Table 14-A. The values quoted are approximate.

The constants tables, Nos. 14-B and 14-C, are for d-c watthour meters using monthly- and daily-reading registers respectively. These tables and some of the following tables are used by indexing from the proper type over to the right voltage, then down to the ampere rating, and from there on the same horizontal line over to the corresponding constant data.

Tables 14-D and 14-E are for older types of d-c watthour meters.

Constants and register ratio data for a-c meters using monthly-reading registers manufactured up to January 1939, approximately serial No. 19,500,000, are obtained by first referring to Table 14-F. After the proper column number has been determined, refer to that column in Table 14-G, find the desired ampere value, and on the same horizontal line the corresponding constant data will be given.

Refer to Section 17 for Standard Register Constants.

Tables 14-F and 14-G contain data for meters in self-contained voltage ratings and in current ratings (with or without current transformers) up to 600 to 800 amperes. Data for meters using instrument transformers in voltage or current ratings other than those included in the tables can be calculated as outlined in Table 14-J.

Table 14-H is for a-c meters using daily-reading registers. For ratings other than those in the table refer to Table 14-J, as for the monthly-reading registers.

Older types of a-c meters are covered by Table 14-I.

All constants tables are prepared principally for standard 4-dial registers. In general, for any given watthour constant a 5-dial register will have 1/10th the register ratio and register constant of a 4-dial register for the same watthour constant.

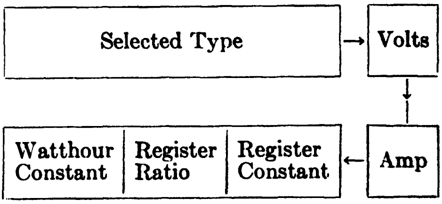


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TABLE 14-A
METER DATA
GENERAL ELECTRIC METERS

Type	First Year Mfd	Data Applies to Meter Size			Approx. Full Load Torque (Mmg)	Weight of Rotating Element (Grams)	Ratio of Torque to Weight	Coil Loss	
		(Amps)	(Volts)	(Cycles)				Current (Watts)	Potential (Watts)
Direct-Current Watthour Meters									
C-6, C-7 & C-8	1905	5	110	....	170	91	1.87	5.7	5.1
		150	110	....	170	99	1.72	9.5	5.1
C-15	1923	5	110	....	122	80	1.52	6.6	5.1
CQ & CQ-2	1909	50	110	....	111	96	1.16	7.5	9.25
CS CS-2	1907 1910	400	110	....	190	170	1.12	....	8.2
		1200	110	....	250	180	1.39	....	6.2
		1500	110	....	300	180	1.67	....	6.2
G-2 G-3	1908 1911	....	....	...	150–300	175–200	0.87–1.5		
Single-Phase Watthour Meters									
IS IS-2 IS-3	1903 1905 1906	5	110	25	55	42	1.36	0.7	1.3
		5	110	60	77	29	2.41	0.7	1.5
I-10	1910	5	110	25	25	25.5	1.0	0.5	1.5
		5	110	60	46	25.5	1.8	0.5	1.5
I-14 (or K-5) IS-4 & IS-5	1914 1915	5	110	25	26.5	12.9	2.05	0.6	1.43
		5	110	60	45	12.9	3.49	0.6	1.17
I-15 IS-6 & IS-7	1925	5	110	25	40	16.5	2.43	0.6	1.8
I-16 & IS-8	1927	5	115	60	52.2	13.2	3.95	0.16	1.3
I-20	1934	5	115	60	52.2	13.2	3.95	0.16	1.3
I-30	1937	5	120	60	50	13.3	3.7	0.3	1.3
I-50	1948	15	120	60	40	16.2	†	0.29	1.3
Polyphase Watthour Meters									
D-3 D-4, DS-2, DS-3 DS-4 & DS-5	1905 1906 1908	5	110	25	114	98	1.12	*1.4	*2.6
		5	110	60	154	69	2.23	*1.4	*3.0
D-6, DS-6, DS-7 D-7	1915 1923	5	110	60	98.5	31	3.55	*1.2	*2.32
D-8, DS-11, DS-12	1925	5	110	25	83	40.7	2.03	*1.2	*3.6
D-9, DS-9	1925	5	110	60	135	58	2.32	*1.8	*3.5
D-13, DS-13	1925	5	110	25	125	58	2.15	*1.8	*5.4
D-14, DS-19	1928	5	115	60	103	35.5	2.9	*0.36	*3.60
D-15, DS-20	1928	5	115	60	155	54.5	2.84	*0.54	*4.90
V-2, V-3	1936	5	120	60	80	21	3.8	*0.6	*2.8
V-4	1938	5	120	60	120	48	2.5	*1.0	*4.2

* Total Watts loss in two in elements for two-element meters and in three elements for three-element meters.
† Ratio does not apply due to magnetic suspension.

TABLE 14-B

CONSTANTS AND REGISTER RATIO DATA

FOR GENERAL ELECTRIC D-C WATTHOUR METERS MONTHLY READING REGISTERS

Types			VOLTAGE (110 for the Range 100–120; 130 for 120–139; 220 for 200–240 and 250 for 220–259)													
G-2 and G-3 (2-Wire)															110	220
HS-11 (2-Wire)											110	130	220	250		
HS-3, HS-4, HS-7 and HS-8 (2-Wire)										110	220					
CS, CS-2, CS-3 and CS-4 (2- and 3-Wire)								110	220							
CQ and CQ-2 (2- and 3-Wire) Later Type						110	220									
CQ and CQ-2 (2- and 3-Wire) Older Type					110	220										
CP, CP-2, CP-3 and CP-4 (2- and 3-Wire)			110	220												
C, C-5, C-6, C-7 C-9, C-12, C-15 and CR (2- and 3-Wire)			110	220												
Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	AMPERE RATING.													
0.125	800	1	(a) 3													
0.2	500	1	5													
0.25	400	1		(a) 3												
0.4	250	1	10	5												
0.6	166 2/3	1	15							10						
0.75	133 1/3	1		10				(c) 15								
1.0	100	1	(b) 25													
1.2	83 1/3	1									10					
1.25	80	1		15				(c) 25								
1.44	69 4/9	1										10				
1.5	66 2/3	1							(c) 15	25						
2.0	50	1	(b) 50	(b) 25	50											
2.4	41 2/3	1											10			
2.5	40	1						50	(c) 25							
2.88	34 13/18	1												10		
3.0	33 1/3	1	(b) 75		75					50	25					
3.6	27 7/9	1										25				
4.0	25	1	(b) 100	(b) 50	100	50		75								
4.5	22 2/9	1								75						
5.0	20	1						100	50							
6.0	16 2/3	1	(b) 150	(b) 75		75				100	50		25			
7.2	13 8/9	1										50		25		
7.5	13 1/3	1		(b) 100	200	100	50	150	75							
9.0	11 1/9	1									(e) 75					
9.0	111 1/9	10								150	(f) 75					
10	10	1						200	100							
10.8	9 7/27	1										75				
12	8 1/3	1									(e) 100		50			
12	83 1/3	10								200	(f) 100					
12.5	80	10	(b) 300	(b) 150			75									
14.4	6 17/18	1										100		50		
15	66 2/3	10			400	200	100	300	150							
18	55 5/9	10								300	150		75			
20	50	10						400	200							
21.6	46 8/27	10										150		75		
24	41 2/3	10								400	200		100			
25	40	10	(b) 600	(b) 300												
28.8	34 13/18	10												100		
30	33 1/3	10				400	200	600	300	500		200				
36	27 7/9	10								600	300		150			
40	25	10						(d) 800	400							
43.2	23 4/27	10												150		
45	22 2/9	10										300				
48	20 5/6	10									400		200			
50	20	10		(b) 600												
60	16 2/3	10					400	(d) 1200	600		500	400		200		
72	13 8/9	10									600	500	300			
75	13 1/3	10						(d) 1500	(d) 800							
90	11 1/9	10										600		300		
96	10 5/12	10									(e) 800		400			
100	100	100													2000	
108	9 7/27	10										800				
120	8 1/3	10									(e) 1000		500	400		
125	80	100							(d) 1200							
144	6 17/18	10										1000		500		
150	6 2/3	10											600			
150	66 2/3	100							(d) 1500						3000	
180	55 5/9	100												600		
192	52 1/12	100											800			
200	50	100													4000	2000
216	46 8/27	100												800		
240	41 2/3	100											1000			
288	34 13/18	100												1000		
300	33 1/3	100													6000	3000
400	25	100													8000	4000
500	20	100													10000	
600	16 2/3	100														6000
750	133 1/3	1000														8000
1000	100	1000														10000

R_g (Gear Ratio) = R_r (Register Ratio) × 100

In all cases the numerical value (disregarding the register constant) of 1 revolution of the first dial pointer is equal to 10.

(a) CP, CP-2, CP-3 and CP-4 Meters Only.
(b) C, C-5, C-6, C-7, C-9, C-12 and CR Meters Only.
(c) CS-3 CS-4 Meters Only.
(d) CS and CS-2 Meters Only.
(e) HS-11 Meters Only.
(f) HS-3, HS-4, HS-7 and HS-8 Meters Only.

TABLE 14-C

CONSTANTS AND REGISTER RATIO DATA

FOR GENERAL ELECTRIC D-C WATTHOUR METERS
DAILY READING REGISTERS

Types			VOLTAGE (110 for the Range 100–120; 130 for 120–139; 220 for 200–240; and 250 for 220–259)														
G-2 and G-3 (2-Wire)																110	220
HS-11 (2-Wire)												110	130	220	250		
HS-3, HS-4, HS-7 and HS-8 (2-Wire)										110	220						
CS, CS-2, CS-3 and CS-4 (2- and 3-Wire)								110	220								
CQ and CQ-2 (2- and 3-Wire) Later Type						110	220										
CQ and CQ-2 (2- and 3-Wire) Older Type					110	220											
C, C-5, C-6, C-7 C-9, C-12 and CR (2- and 3-Wire)			110	220													
Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	AMPERE RATING														
0.2	50	* 1	5														
0.4	25	* 1	10	5													
0.6	16 2/3	* 1	15							10							
0.75	13 1/3	* 1		10				(a) 15									
1.0	10	* 1	25														
1.2	8 1/3	* 1									10	10					
1.25	8	* 1		15				(a) 25									
1.44	6 17/18	* 1											10				
1.5	6 2/3	* 1							(a) 15	25							
2.0	5	* 1	50	25	50												
2.4	4 1/6	* 1												10			
2.5	4	* 1						50	(a) 25								
2.88	3 17/36	* 1													10		
3.0	3 1/3	* 1	75		75					50	25	25					
3.6	2 7/9	* 1											25				
4.0	2 1/2	* 1	100	50	100	50		75									
4.5	2 2/9	* 1								75							
5.0	2	* 1						100	50								
6.0	1 2/3	* 1	150	75		75				100	50	50		25			
7.2	1 7/18	* 1											50		25		
7.5	1 1/3	* 1		100	200	100	50	150	75								
9.0	1 1/9	* 1										75					
9.0	11 1/9	1								150	75						
10.0	1	* 1						200	100								
10.8	9 7/27	1											75				
12	8 1/3	1								200	100	100		50			
12.5	8	1	300	150			75										
14.4	6 17/18	1											100		50		
15	6 2/3	1			400	200	100	300	150								
18	5 5/9	1								300	150	150		75			
20	5	1						400	200								
21.6	4 17/27	1											150		75		
24	4 1/6	1								400	200	200		100			
25	4	1	600	300													
28.8	3 17/36	1													100		
30	3 1/3	1				400	200	600	300	500			200				
36	2 7/9	1								600	300	300		150			
40	2 1/2	1						(b) 800	400								
43.2	2 17/34	1													150		
45	2 2/9	1											300				
48	2 1/12	1									400	400		200			
50	2	1		600													
60	1 2/3	1					400	(b) 1200	600		500	500	400		200		
72	1 7/18	1									600	600	500	300			
75	1 1/3	1						(b) 1500	(b) 800								
90	1 1/9	1											600		300		
96	1 1/24	1										800		400			
100	1	1														2000	
108	9 7/27	10											800				
120	8 1/3	10										1000		500	400		
125	8	10							(b) 1200								
144	6 17/18	10											1000		500		
150	6 2/3	10							(b) 1500					600		3000	
180	5 5/9	10													600		
192	5 5/24	10												800			
200	5	10														4000	2000
216	4 17/27	10													800		
240	4 1/6	10												1000			
288	3 17/36	10													1000		
300	3 1/3	10														6000	3000
400	2 1/2	10														8000	4000
500	2	10														10000	
600	1 2/3	10															6000
750	1 1/3	10															8000
1000	1	10															10000

R_g (Gear Ratio) = R_r (Register Ratio) × 100

The numerical value (disregarding the register constant) of 1 revolution of the 1st dial pointer is equal to 10, except where indicated by an asterisk (*), in which case the numerical value is equal to 1 (black dial).

(a) CS-3 and CS-4 meters only.

(b) CS and CS-2 meters only.

TABLE 14-D

CONSTANTS AND REGISTER RATIO DATA

FOR GENERAL ELECTRIC D-C WATTHOUR METERS BASED ON "RATIO OF GEARS"

Types			VOLTAGE (110 for the Range 100–110, 220 for 200–220)							
G (2-Wire) formerly CF, Form GG-4									110	220
Form G-2 (2-Wire) High Capacity							110	220		
E-1 (2- and 3-Wire)					110	220				
Form J-2 & D-2 (2- and 3-Wire)			110	220						
Watthour Constant (K_h)	Ratio of Gears**	Register Constant (K_r)*	AMPERE RATING							
0.125	0.125	1	3							
0.2	0.2	1	5							
0.25	0.25	1		(a) 3						
0.25	0.25	1		(b) 3.5						
0.4	0.4	1	10	(a) 5						
0.6	0.6	1	15	(b) 7.5						
0.75	0.75	1		(a) 10						
1.0	1.0	1	25							
1.25	1.25	1		15						
2	0.2	10	50	25						
3	0.3	10	75							
4	0.4	10	100	50						
6	0.6	10	150	75						
7.5	0.75	10	200	100						
12.5	1.25	10	300	150						
15	1.5	10		200						
20	0.2	100	450							
25	0.25	100	600	300						
40	0.4	100		(a) 450	800					
50	0.5	100	1200	(a) 600						
60	0.6	100			1200					
75	0.75	100			1500	800				
100	1.0	100		(a) 1200					2000	
125	1.25	100				1200	2500			
150	1.5	100				1500			3000	
200	0.2	1000					4000		4000	2000
250	0.25	1000					5000	2500		
300	0.3	1000					6500		6000	3000
400	0.4	1000					8000	4000	8000	4000
500	0.5	1000					10000	5000	10000	
600	0.6	1000						6500		6000
750	0.75	1000						8000		8000
1000	1.0	1000						10000		10000

* These meters have registers for which 1 revolution of the 1st dial pointer (disregarding the register constant) is equal to 1000 watthours. This corresponds to a numerical value of 1 (kwhr) in later meters.

** Ratio of Gears equals the number of divisions passed over by the 1st dial pointer per revolution of the worm wheel, or, the fraction of a revolution of the 1st dial pointer per 10 revolutions of the worm wheel. This is not the Gear Ratio as defined in Section 9. The relation between Ratio of Gears and Register Ratio or Gear Ratio is as follows:

$$\text{Register Ratio } (R_r) = \frac{10}{\text{Ratio of Gears}} \qquad \text{Gear Ratio } (R_g) = \frac{1000}{\text{Ratio of Gears}}$$

(a) 2-wire rating only.

(b) 3-wire rating only.

TABLE 14-E

CONSTANTS AND REGISTER RATIO DATA

FOR GENERAL ELECTRIC D-C WATTHOUR METERS NON-DIRECT READING REGISTERS

Forms			VOLTAGE (110 for the Range 100–110, 220 for 200–220)			
G-2 (2-Wire) High Capacity					110	220
J, JN, J-1, FN, DN & D-1 (2- & 3-Wire)			110	220		
Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)*	AMPERE RATING			
0.2	10	1/5	3			
0.25	10	1/4		(a) 3		
0.25	10	1/4		(b) 3.5		
0.5	10	1/2	5			
0.5	10	1/2	10	(a) 5		
1	10	1	15	(b) 7.5		
1	10	1	25	(a) 10		
2	10	2		15		
2	10	2	50	25		
3	10	3	75			
4	10	4	100	50		
6	10	6	150	75		
8	10	8	200	100		
12	10	12	300	150		
16	10	16		200		
20	10	20	450			
24	10	24	600	300		
36	10	36		(a) 450		
48	10	48	1200	(a) 600		
96	10	96		(a) 1200		
125	10	125			2500	
200	10	200			4000	
250	10	250			5000	2500
300	10	300			6500	
400	10	400			8000	4000
500	10	500			10000	5000
600	10	600				6500
800	10	800				8000
1000	10	1000				10000

R_g (Gear Ratio) = R_r (Register Ratio) × 100.

* These meters have registers for which 1 revolution of the 1st dial pointer (disregarding the register constant) is equal to 1000 watthours. This corresponds to a numerical value of 1 (kwhr) in later meters.

(a) 2-wire rating only. (b) 3-wire rating only.

TABLE 14-F

METER TYPES FOR CONSTANTS AND REGISTER RATIO DATA FOR GENERAL ELECTRIC WATTHOUR METERS MONTHLY READING REGISTERS

SINGLE PHASE METERS

Type	Frequency (Cycles)	Pot. Rating (Volts)	Remarks	See Table No. 14-G Column No.
K	25–35	100–125		9
		200–250		21
	60	100–125	Below Serial No. 345,000	1
			From Serial No. 345,000 to Serial No. 576,000 incl.	2
			Above Serial No. 576,000	3
		200–250	Below Serial No. 345,000	7
			From Serial No. 345,000 to Serial No. 576,000 incl.	8
			Above Serial No. 576,000	10
K-1, K-2 & K-3	25–35	100–125		9
		200–250		21
	60	100–125	From Serial No. 345,000 to Serial No. 576,000 incl.	2
			Above Serial No. 576,000	3
		200–250	From Serial No. 345,000 to Serial No. 576,000 incl.	8
			Above Serial No. 576,000	10
K-4	25–35	100–125		9
		200–250		21
	60	100–125		2
		200–250		9
K-5	25–60	100–120	Below Serial No. 5,000,000	5
			Serial No. 5,000,000 and above	4
		200–240	Below Serial No. 5,000,000	14
			Serial No. 5,000,000 and above	13
I	25–35	106–120		16
		212–240		31
	56–60	106–120		6
		212–240		16
I-8	25–35	106–120		16
		212–240		31
	56–60	106–120		6
		212–240		16
I-10	25–30	106–120		6
		212–240		16
	40–60	106–120		2
		212–240		9

Type	Frequency (Cycles)	Pot. Rating (Volts)	Remarks	See Table No. 14-G Column No.
I-14	25–60	100–120	Below Serial No. 5,000,000	5
			Serial No. 5,000,000 and above	4
		200–240	Below Serial No. 5,000,000	14
			Serial No. 5,000,000 and above	13
I-15	25–30	100–120		12
		200–240		26
I-16	25–60	100–120	Self-Contained Meter	12
			2.5 Amp Meter used with cur. transf.	4
		200–240	Self-Contained Meter	26
			2.5 Amp Meter used with cur. transf.	13
I-20	25–60	100–120	Self-Contained Meter	12
			2.5 Amp Meter used with cur. transf.	4
		200–240	Self-Contained Meter	26
			2.5 Amp Meter used with cur. transf.	13
I-30	60	100–120	Self-Contained Meter	11
			2.5 Amp Meter used with cur. transf.	4
		200–240	Self-Contained Meter	25
			2.5 Amp Meter used with cur. transf.	13
I-30	60	100–120	Self-Contained Meter	12
		200–240	Self-Contained Meter	26
IP, IP-2 IP-3 & IP-4	25–35	106–120		16
		212–240		31
	56–60	106–120		6
		212–240		16
IP-5	25–60	100–120		4
		200–240		13
IS-4 & IS-5	25–60	100–120		4
		200–240		13
IS-6 & IS-7	25–30	100–120		12
		200–240		26
IS-8 & IS-9	25–60	100–120	Self-Contained Meter	12
			2.5 Amp Meter used with cur. transf.	4
		200–240	Self-Contained Meter	26
			2.5 Amp Meter used with cur. transf.	13

POLYPHASE METERS

Type	Frequency (Cycles)	Pot. Rating (Volts)	Remarks	See Table No. 14-G Column No.
K (2 El. Polyphase)	25–60	100–125	Below Serial No. 345,000	17
			From Serial No. 345,000 to Serial No. 576,000 incl.	20
		200–250	Below Serial No. 345,000	36
			From Serial No. 345,000 to Serial No. 576,000 incl.	39
		400–499	Below Serial No. 345,000	55
			From Serial No. 345,000 to Serial No. 576,000 incl.	57
		500–625	Below Serial No. 345,000	60
			From Serial No. 345,000 to Serial No. 576,000 incl.	62
K-1 (2 El. Polyphase)	25–60	100–125	From Serial No. 345,000 to Serial No. 576,000 incl.	20
			Above Serial No. 576,000	21
		200–250	From Serial No. 345,000 to Serial No. 576,000 incl.	39
			Above Serial No. 576,000	40
K-3 (2 El. Polyphase)	25–35	100–125		21
		200–250		40
		400–499		58
		500–625		63
	60	100–125		10
		200–250		23
		400–499		42
		500–625		49

Type	Frequency (Cycles)	Pot. Rating (Volts)	Remarks	See Table No. 14-G Column No.
D-3 & D-4 (2 El. Polyphase)	25–30	106–120		32
		212–240		53
		400–480		65
		500–600		66
	40–50	106–120		18
		212–240		37
		400–480		54
		500–600		61
	60	106–120		18
		212–240		30
		400–480		48
		500–600		53

TABLE 14-F (Continued)—GENERAL ELECTRIC Meter Types For Constants and Register Ratio Data

MONTHLY READING REGISTERS

Polyphase Meters

Type	Frequency (Cycles)	Pot. Rating (Volts)	Remarks	See Table No. 14-G Column No.
D-6 & D-7* (2 El. Polyphase)	25–60	100-120	Below Serial No. 5,000,000	14
			Serial No. 5,000,000 and above	13
		200-240*	Below Serial No. 5,000,000	29
			Serial No. 5,000,000 and above	28
		400-480	Below Serial No. 5,000,000	47
			Serial No. 5,000,000 and above	46
D-6 & D-7* (2 El. Polyphase)	25–60	500-600	Below Serial No. 5,000,000	51
			Serial No. 5,000,000 and above	50
		100-120Y 173-208Δ	Below Serial No. 5,000,000	24
			Serial No. 5,000,000 and above	22
		200-240Y 346-416Δ	Below Serial No. 5,000,000	43
			Serial No. 5,000,000 and above	41
D-8* (2 El. Polyphase)	25–30	100-120		26
		200-240*		44
		400-480		50
		500-600		64
		100-120Y 173-208Δ		38
		200-240Y 346-416Δ		56
D-9* (3 El. Polyphase)	25–60	100-120Y 173-208Δ		22
		200-240Y* 346-416Δ		41
D-13* (3 El. Polyphase)	25–30	100-120Y 173-208Δ		38
		200-240Y* 346-416Δ		56
D-14* (2 El. Polyphase)	25–60	100-120	Self-Contained Meter	26
			2.5 Amp Meter used with cur. transf.	13
		200-240*	Self-Contained Meter	44
			2.5 Amp Meter used with cur. transf.	27
		400-480	Self-Contained Meter	59
			2.5 Amp Meter used with cur. transf.	45
		500-600	Self-Contained Meter	64
			2.5 Amp Meter used with cur. transf.	50
		100-120Y 173-208Δ	Self-Contained Meter	33
			2.5 Amp Meter used with cur. transf.	19
		200-240Y 346-416Δ	Self-Contained Meter	53
			2.5 Amp Meter used with cur. transf.	34
D-15* (3 El. Polyphase)	25–60	100-120Y 173-208Δ	Self-Contained Meter	33
			2.5 Amp Meter used with cur. transf.	19
		200-240Y* 346-416Δ	Self-Contained Meter	53
			2.5 Amp Meter used with cur. transf.	34
DS-6 & DS-7 (2 El. Polyphase)	25–60	100-120		13
		200-240		27
		400-480		45
		500-600		50
		100-200Y 173-208Δ		22
		200-240Y 346-416Δ		41
DS-9 (3 El. Polyphase)	25–60	100-120Y 173-208Δ		22
		200-240Y 346-416Δ		41
DS-11 & DS-12 (2 El. Polyphase)	25–30	100-120		26
		200-240		44
		400-480		59
		500-600		64
		100-120Y 173-208Δ		38
		200-240Y 346-416Δ		56
DS-13 (3 El. Polyphase)	25–30	100-120Y 173-208Δ		38
		200-240Y 346-416Δ		56
DS-19, DS-21, DS-34, DS-38, & DS-40 (2 El. Polyphase)	25–60	100-120	Self-Contained Meter	26
			2.5 Amp Meter used with cur. transf.	13
		200-240	Self-Contained Meter	44
			2.5 Amp Meter used with cur. transf.	27
		400-480	Self-Contained Meter	59
			2.5 Amp Meter used with cur. transf.	45

Type	Frequency (Cycles)	Pot. Rating (Volts)	Remarks	See Table No. 14-G Column No.
DS-19, DS-21, DS-34, DS-38, & DS-40 (2 El. Polyphase)	25–60	500-600	Self-Contained Meter	64
			2.5 Amp Meter used with cur. transf.	50
		100-120Y 173-208Δ	Self-Contained Meter	33
			2.5 Amp Meter used with cur. transf.	19
		200-240Y 346-416Δ	Self-Contained Meter	53
			2.5 Amp Meter used with cur. transf.	34
DS-20, DS-23, DS-35, DS-39, & DS-41 (3 El. Polyphase)	25–60	100-120Y 173-208Δ	Self-Contained Meter	33
			2.5 Amp Meter used with cur. transf.	19
		200-240Y 346-416Δ	Self-Contained Meter	53
			2.5 Amp Meter used with cur. transf.	34
I-18 (2 El. 3 Wire)	50-60	100-120		26
		200-240		44
V-2 (2 El. 3-Wire)	50-60	100-120		26
		200-240		44
		400-480		59
		500-600		64
V-3 (2 El. Polyphase)	50-60	100-120	Self-Contained Meter	26
			2.5 Amp Meter used with cur. transf.	13
		200-240	Self-Contained Meter	44
			2.5 Amp Meter used with cur. transf.	27
		400-480	Self-Contained Meter	59
			2.5 Amp Meter used with cur. transf.	45
		500-600	Self-Contained Meter	64
			2.5 Amp Meter used with cur. transf.	50
V-6 (2 El. Polyphase)	50-60	200-240	Self-Contained Meter	44
			2.5 Amp Meter used with cur. transf.	27
V-5 (2½ El. Polyphase)	50-60	100-120Y 173-208Δ	Self-Contained Meter	33
			2.5 Amp Meter used with cur. transf.	19
V-4 (3 El. Polyphase)	50-60	100-120Y 173-208Δ	Self-Contained Meter	33
			2.5 Amp Meter used with cur. transf.	19
V-7 (3 El. Polyphase)	50-60	200-240	Self-Contained Meter	53
			2.5 Amp Meter used with cur. transf.	34
V-9 (3 El. Polyphase)	50-60	200-240	Self-Contained Meter	53
			2.5 Amp Meter used with cur. transf.	34
V-10 (3 El. Polyphase)	50-60	200-240	Self-Contained Meter	53
			2.5 Amp Meter used with cur. transf.	34
V-8 (2 El. Polyphase)	50-60	200-240	Self-Contained Meter	44
			2.5 Amp Meter used with cur. transf.	27

TABLE

CONSTANTS AND REGISTER RATIO DATA FOR MONTHLY READ

Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	COLUMN NO.																																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
			AMPERE RATING																																
0.2	500	1						3																											
0.25	400	1	5	5	5																														
0.3	333 1/3	1				5	5	5																											
0.36	277 7/9	1																																	
0.4	250	1															3	3																	
0.5	200	1	10	10	10				5	5	5	5																							
0.6	166 2/3	1				10	10	10					5	5	5	5	5	5		3															
0.72	138 8/9	1																																	
0.75	133 1/3	1		15	15																											3	3		
0.9	111 1/9	1				15	15														5														
1	100	1	15																																
1	100	1	20	20	20			15	10	10	10	10							5	5		5	5	5	5	5								3	
1	100	1	25																																
1.08	92 16/27	1																																	
1.2	83 1/3	1												10	10	10											5	5	5	5	5				
1.25	80	1		25	25												10	10														5	5		
1.44	69 4/9	1																																	
1.444+	69 3/13	1																																	
1.5	66 2/3	1				25	25	25	15	15	15	15	15																					5	
1.8	55 5/9	1												15	15	15					10														5
2	50	1	30																																
2	50	1	40	40	40				20	20	20	20					15	15	10	10		10	10	10	10	10									
2	50	1	50						25																										
2.16	46 8/27	1																																	
2.166+	46 2/13	1																																	
2.4	41 2/3	1																										10	10	10	10				
2.5	40	1		50	50				30	25	25	25																				10	10		
2.7	37 1/27	1																			15														
2.88	34 13/18	1																																	
2.882+	34 34/49	1																																	
3	33 1/3	1	60			50	50	50	40		30	30		25	25	25	25	25	15	15		15	15	15	15	15	15							10	
3	33 1/3	1	75																																
3.24	30 70/81	1																																	
3.6	27 7/9	1																										15	15	15					10
3.6	277 7/9	10																													15				
3.75	26 2/3	1		75	75																														
4	25	1	100						50	40	40	40							20			20	20		20							15	15		
4	25	1																	25																
4	250	10																																	
4.318+	231 11/19	10																																	
4.32	23 4/27	1																																	
4.5	22 2/9	1				75																													
4.5	222 2/9	10					75														25														
4.8	20 5/6	1																																	
4.8	208 1/3	10																																	
5	20	1	125	100				75	60	50	50									25		25	25	25										15	
5	200	10			100							50													25	25									
5.4	18 14/27	1																																	15
5.405	185	10																																	
5.757	173 13/19	10																																	
5.76	17 13/36	1																																	
6	16 2/3	1	150			100		100	75		60		50	50	50		50	50	30				30					25	25	25		25	25		
6	166 2/3	10					100					60				50									30						25				
6.25	16	1		125																															
6.25	160	10			125																														
6.48	15 35/81	1																																	
7.2	13 8/9	1																																	
7.2	138 8/9	10																																	
7.5	13 1/3	1		150						75	75						75																	25	
7.5	133 1/3	10			150							75																							
8	12 1/2	1	200						100		80								40			40	40												
8	12 1/2	1																	50																
8	125	10										80													40										
8.64	11 31/54	1																																	
8.64	115 20/27	10																																	
8.648+	115 5/8	10																																	
9	11 1/9	1												75																					25
9	111 1/9	10				150	150								75	75					50														
9.6	10 5/12	1																																	
9.6	104 1/6	10																																	
10	10	1	250	200				150	125	100								75		50		50													
10	100	10			200						100	100											50	50	50	50									
10.08	99 13/63	10																																	
10.5	95 5/21	10																																	
10.8	9 7/27	1																																	
10.8	92 16/27	10																																	
11.25	88 8/9	10																																	
11.51+	86 16/19	10																																	
11.52	8 49/72	1																																	
11.52	86 29/36	10																																	

14-G

GENERAL ELECTRIC A-C WATTHOUR METERS

ING REGISTERS

COLUMN NO.																																	Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)
34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66			
AMPERE RATING																																			
																																	0.2	500	1
																																	0.25	400	1
																																	0.3	333 1/3	1
																																	0.36	277 7/9	1
																																	0.4	250	1
																																	0.5	200	1
																																	0.6	166 2/3	1
																																	0.72	138 8/9	1
																																	0.75	133 1/3	1
																																	0.9	111 1/9	1
																																	1	100	1
																																	1	100	1
																																	1	100	1
																																	1.08	92 16/27	1
																																	1.2	83 1/3	1
			3																														1.25	80	1
																																	1.44	69 4/9	1
																																	1.444+	69 3/13	1
														3																			1.5	66 2/3	1
																																	1.8	55 5/9	1
																																	2	50	1
		5	5	5	5	5	5	5	5									3															2	50	1
																																	2	50	1
																																	2.16	46 8/27	1
																																	2.166+	46 2/13	1
										5	5	5	5																				2.4	41 2/3	1
														5	5					3													2.5	40	1
																																	2.7	37 1/27	1
																																	2.88	34 13/18	1
																																	2.882+	34 34/49	1
																5	5	5									3						3	33 1/3	1
																																	3	33 1/3	1
																																	3.24	30 70/81	1
																			5														3.6	27 7/9	1
																																	3.6	277 7/9	10
																																	3.75	26 2/3	1
		10	10	10	10	10	10	10												5	5	5	5	5							2		4	25	1
																																	4	25	1
									10																								4	250	10
																																	4.318+	231 11/19	10
																																	4.32	23 4/27	1
																																	4.5	22 2/9	1
																																	4.5	222 2/9	10
										10	10	10													5								4.8	20 5/6	1
													10																				4.8	208 1/3	10
														10												5	5	5	5			2	5	20	1
															10																		5	200	10
15																																	5.4	18 14/27	1
																																	5.405	185	10
																																	5.757	173 13/19	10
																																	5.76	17 13/36	1
		15	15	15	15	15	15									10		10												5	5		6	16 2/3	1
								15	15								10																6	166 2/3	10
																																	6.25	16	1
																																	6.25	160	10
																																	6.48	15 35/81	1
										15	15	15							10														7.2	13 8/9	1
													15																				7.2	138 8/9	10
														15						10												5	7.5	13 1/3	1
															15																		7.5	133 1/3	10
		20			20	20															10	10	10	10									8	12 1/2	1
		25																															8	12 1/2	1
								20																									8	125	10
																																	8.64	11 31/54	1
																																	8.64	115 20/27	10
																																	8.648+	115 5/8	10
																																	9	11 1/9	1
25																15	15																9	111 1/9	10
																									10								9.6	10 5/12	1
																																	9.6	104 1/6	10
		30	25	25	25													15								10	10	10					10	10	1
						25	25	25	25						20														10				10	100	10
																																	10.08	99 13/63	10
																																	10.5	95 5/21	10
																			15														10.8	9 7/27	1
																																	10.8	92 16/27	10
																																	11.25	88 8/9	10
																																	11.51+	86 16/19	10
																																	11.52	8 49/72	1
																																	11.52	86 29/36	10

TABLE 14-G (Continued)—GENERAL ELECTRIC

Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	COLUMN NO.																																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
			AMPERE RATING																																
12	8 1/6	1							150					100					60								50	50							
12	8 1/3	1																	75																
12	83 1/3	10				200	200								100	100							60		60				50	50	50				
12.5	8	1																																	
12.5	80	10						200		125	125	125					100	100		75												50	50		
12.6	7 59/63	1																																	
12.6	79 23/63	10																																	
12.96	77 13/81	10																																	
13.5	74 2/27	10																			75														
14.4	6 17/18	1																																	
14.4	69 4/9	10																																	
14.44 +	69 3/13	10																																	
15	6 2/3	1	300																																
15	66 2/3	10		300	300					150	150	150					150					75	75	75	75	75						75		50	
15.12	66 26/189	10																																	
15.75	63 31/63	10																																	
16	6 1/4	1							200										100																
16	6 1/4	1																																	
16	62 1/2	10																					80		80										
16.2	61 59/81	10																																	
16.8	59 11/21	10																																	
17.28	57 47/54	10																																	
17.30	57 7/9	10																																	
18	55 5/9	10				300	300							150	150	150					100							75	75	75	75				50
18.9	52 172/189	10																																	
19.2	52 1/12	10																																	
20	5	1	400						250										125																
20	5	1																																	
20	50	10		400	400			300		200	200	200						150		100		100	100	100	100	100							75	75	
21	47 13/21	10																																	
21.6	46 8/27	10																																	
21.66 +	46 2/13	10																																	
22.5	44 4/9	10																																	
23.04	43 29/72	10																																	
23.07 +	43 1/3	10																																	
24	4 1/6	1																	150																
24	4 1/6	1																																	
24	41 2/3	10				400	400							200	200	200												100	100	100	100				
25	4	1																																	
25	40	10															200	200		150		125	125		125							100	100		
25.2	39 43/63	10																																	
25.92	38 47/81	10																																	
27	37 1/27	10																			150														
28.8	34 13/18	10																																	
28.82	34 34/49	10																																	
30	3 1/3	1																																	
30	33 1/3	10	600	600	600	500	500		300	300	300	300										150	150	150	150	150						150		100	
31.5	31 47/63	10																																	
32	3 1/8	1																																	
32	3 1/8	1																																	
32	31 1/4	10																																	
32	312 1/2	100																																	
32.4	30 70/81	10																																	
33.6	29 16/21	10																																	
33.6	297 13/21	100																																	
34.56	28 101/108	10																																	
36	27 7/9	10				600								300	300						200							150	150	150					
36	277 7/9	100					600									300															150				
37.5	26 2/3	10																																	
37.5	266 2/3	100																																	
37.8	26 86/189	10																																	
38.4	26 1/24	10																																	
38.46 +	200	100																																	
40	2.5	1																																	
40	25	10	800	800	800				400	400	400	400					300	300	200	200		200	200	200	200								150	150	
40	25	10																																	
40	250	100																							200										
40.5	24 56/81	10																																	
42	23 17/21	10																																	
42	238 2/21	100																																	
43.18 +	231 11/19	100																																	
43.2	23 4/27	10																																	
45	22 2/9	10																																	
45	222 2/9	100																																	
46.08	21 101/144	10																																	
48	20 5/6	10												400	400													200	200	200					
48	20 5/9	10																																	
48	208 1/3	100														400															200				
50	2	1																																	
50	20	10															400															200	200		
50	200	100																																	
50.4	19 53/63	10																																	
50.4	198 26/63	100																																	
51.84	19 47/162	10																																	
54	18 14/27	10																			300														

Constants and Register Ratio Data

COLUMN NO.																																	Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)
34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66			
AMPERE RATING																																			
										25											15	15								10			12	8 1/3	1
																																	12	8 1/3	1
						30		30			25	25	25										15	15									12	83 1/3	10
																																	12.5	8	1
														25	25					15											10		12.5	80	10
																																	12.6	7 59/63	1
																																	12.6	79 23/63	10
																																	12.96	77 13/81	10
																																	13.5	74 2/27	10
																									15								14.4	6 17/18	1
																																	14.4	69 4/9	10
																																	14.44 +	69 3/13	10
																										15							15	6 2/3	1
															30	25	25	25									15	15	15			10	15	66 2/3	10
																																	15.12	66 26/189	10
																																	15.75	63 31/63	10
		40																			20												16	6 1/4	1
		50																			25												16	6 1/4	1
					40	40		40															20	20									16	62 1/2	10
																																	16.2	61 59/81	10
																																	16.8	59 11/21	10
																																	17.28	57 47/54	10
																																	17.30	57 7/9	10
50																			25											15			18	55 5/9	10
																																	18.9	52 172/189	10
																																	19.2	52 1/12	10
																					30					20							20	5	1
																										25							20	5	1
			50	50	50	50	50	50	50						40					25		25	25	25				20	20		15		20	50	10
																																	21	47 13/21	10
																																	21.6	46 8/27	10
																																	21.66 +	46 2/13	10
																																	22.5	44 4/9	10
																																	23.04	43 29/72	10
																																	23.07 +	43 1/3	10
		60																															24	4 1/6	1
		75																															24	4 1/6	1
						60		60		50	50	50	50											30	25								24	41 2/3	10
																																	25	4	1
			75											50	50												25	25	25			15	25	40	10
																																	25.2	39 43/63	10
																																	25.92	38 47/81	10
75	75																																27	37 1/27	10
																																	28.8	34 13/18	10
																																	28.82	34 34/49	10
																																	30	3 1/3	1
				75	75	75	75	75	75					75	60	50	50	50								30			30	25	25		30	33 1/3	10
																																	31.5	31 47/63	10
		100																			40												32	3 1/8	1
																					50												32	3 1/8	1
						80		80															40	40									32	31 1/4	10
																																	32	312 1/2	100
																																	32.4	30 70/81	10
																																	33.6	29 16/21	10
																																	33.6	297 13/21	100
100	100									75	75	75							50														34.56	28 101/108	10
													75																				36	27 7/9	10
															75																		36	277 7/9	100
																																	37.5	26 2/3	10
																																	37.5	266 2/3	100
																																	37.8	26 86/189	10
																																	38.4	26 1/24	10
																																	38.46 +	260	100
																																	40	2.5	1
		125	100	100	100	100	100	100							80			75		50		50	50	50		40		40	40			25	40	25	10
																										50							40	25	10
									100																								40	250	100
																																	40.5	24 56/81	10
																																	42	23 17/21	10
																																	42	238 2/21	100
																																	43.18 +	231 11/19	100
																																	43.2	23 4/27	10
																75																	45	22 2/9	10
																	75																45	222 2/9	100
																																	46.08	21 101/144	10
										100	100	100									60			60	50								48	20 5/6	10
																					75												48	20 5/9	10
													100																				48	208 1/3	100
																																	50	2	1
		150	150		125	125								100						75							50	50	50				50	20	10
								125							100																		50	200	100
																																	50.4	19 53/63	10
																																	50.4	198 26/63	100
																																	51.84	19 47/162	10
150	150																																54	18 14/27	10

TABLE 14-G (Continued)—GENERAL ELECTRIC

Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	COLUMN NO.																																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
			AMPERE RATING																																
54.05+	185	100																																	
57.57+	173 13/19	100																																	
57.6	17 13/36	10																																	
60	16 2/3	10																																	
60	16 2/3	10							600	600	600			500	500		500		300	300		300	300	300										200	
60	166 2/3	100										600				500									300	300									
62.5	160	100																																	
63	15 55/63	10																																	
63	158 46/63	100																																	
64	15 5/8	10																																	
64.8	15 35/81	10																																	
67.2	14 37/42	10																																	
67.2	148 17/21	100																																	
67.5	14 22/27	10																																	
69.12	14 101/216	10																																	
72	13 8/9	10												600	600						400							300	300	300					
72	138 8/9	100														600															300				
75	1 1/3	1																																	
75	13 1/3	10															600			400												300	300		
75	133 1/3	100																																	
75.6	13 43/189	10																																	
76.8	13 1/48	10																																	
80	12 1/2	10							800	800	800												400												
80	125	100										800												400	400	400									
81	12 28/81	10																																	
84	11 19/21	10																																	
84	119 1/21	100																																	
86.4	11 31/54	10																																	
86.4	115 20/27	100																																	
86.48+	115 5/8	100																																	
90	11 1/9	10																																	
90	111 1/9	100																			500														
94.5	105 155/189	100																																	
96	10 5/12	10																										400							
96	104 1/6	100																											400	400	400				
100	1	1																																	
100	10	10																	500												400		300	
100	100	100																					500		500										
108	92 16/27	100																			600														
120	8 1/3	10																										500							
120	83 1/3	100																				600	600	600	600			500	500	500				
125	8	10																																	
125	80	100																	600												500		400	
144	6 17/18	10																										600							
144	69 4/9	100																											600						
144.4+	69 3/13	100																												600	600				
150	6 2/3	10																																	
150	66 2/3	100																														600		500	
160	6 1/4	10																																	
160	62 1/2	100																				800		800											
180	55 5/9	100																																	
192	52 1/12	100																																	
200	5	10																																	
200	50	100																																600	
216	46 8/27	100																																	
240	4 1/6	10																																	
240	41 2/3	100																																	
250	4	10																																	
250	40	100																																	
288	34 13/18	100																																	
288.2+	34 34/49	100																																	
300	3 1/3	10																																	
300	33 1/3	100																																	
320	31 1/4	100																																	
360	27 7/9	100																																	
360	277 7/9	1000																																	
384	26 1/24	100																																	
400	2.5	10																																	
400	25	100																																	
480	20 5/6	100																																	
500	2	10																																	
500	20	100																																	
576	17 13/36	100																																	
600	16 2/3	100																																	
600	16 2/3	100																																	
640	15 5/8	100																																	
720	13 8/9	100																																	
750	1 1/3	10																																	
750	13 1/3	100																																	
800	12 1/2	100																																	
1000	1	10																																	
1000	10	100																																	

R_g (Gear Ratio) = R_r (Register Ratio) × 100.
In all cases the numerical value (disregarding the register constant) of one revolution of the first dial pointer is equal to 10.

Refer to Table No. 14-J for Constant and Register Ratio Data for A-C watthour meters used with instrument transformers of other ratings than listed here. After determining the primary watthour constant from Table No. 14-J the first three columns of this table may be used to determine the constant and register ratio of the meter. If the primary watthour constant is higher than 100,

Constants and Register Ratio Data

COLUMN NO.																																	Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)
34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66			
AMPERE RATING																																			
																																	54.05+	185	100
																																	57.57+	173 13/19	100
																																	57.6	17 13/36	10
																										60							60	16 2/3	10
				150	150	150	150							150		100		100				75	75	75		75	75		60	50	50		60	16 2/3	10
								150	150								100																60	166 2/3	100
															125																		62.5	160	100
																																	63	15 55/63	10
																																	63	158 46/63	100
																					100			80									64	15 5/8	10
																																	64.8	15 35/81	10
																																	67.2	14 37/42	10
																																	67.2	148 17/21	100
																																	67.5	14 22/27	10
																																	69.12	14 101/216	10
200	200									150	150	150													75								72	13 8/9	10
													150																				72	138 8/9	100
																																	75	1 1/3	1
			200															150		100								75	75		75	50	75	13 1/3	10
															150																		75	133 1/3	100
																																	75.6	13 43/189	10
																																	76.8	13 1/48	10
		200		200	200	200															125	100	100	100		100			80				80	12 1/2	10
							200	200	200																								80	125	100
																																	81	12 28/81	10
																																	84	11 19/21	10
																																	84	119 1/21	100
																																	86.4	11 31/54	10
																																	86.4	115 20/27	100
																																	86.48+	115 5/8	100
																														75			90	11 1/9	10
																150	150																90	111 1/9	100
																																	94.5	105 155/189	100
										200															100								96	10 5/12	10
											200	200	200																				96	104 1/6	100
																																	100	1	1
														200						150	150		125			125	100	100				75	100	10	10
															200									125					100				100	100	100
300	300																																108	92 16/27	100
		300		300																		150				150				100			120	8 1/3	10
					300	300	300	300	300							200	200						150	150									120	83 1/3	100
																																	125	8	10
			300															200									150	125	125		100		125	80	100
										300															150								144	6 17/18	10
400	400										300																						144	69 4/9	100
												300	300																				144.4+	69 3/13	100
																																	150	6 2/3	10
			400											300	300					200								150	150		150	100	150	66 2/3	100
																					200												160	6 1/4	10
				400		400	400	400	400													200	200	200									160	62 1/2	100
500	500															300	300													150			180	55 5/9	100
										400	400	400	400												200								192	52 1/12	100
																										200							200	5	10
			500	500			500		500					400	400			300									200	200	200			150	200	50	100
600	600																																216	46 8/27	100
																					300												240	4 1/6	10
				600		600	600	600	600	500	500	500	500			400	400					300	300	300						200			240	41 2/3	100
																																	250	4	10
			600											500				400		300											200		250	40	100
										600	600														300								288	34 13/18	100
												600	600																				288.2+	34 34/49	100
																																	300	3 1/3	10
														600	600	500	500	500		400						300	300	300	300			200	300	33 1/3	100
						800		800														400		400									320	31 1/4	100
																600														300			360	27 7/9	100
																	600																360	277 7/9	1000
																									400								384	26 1/24	100
																																	400	2.5	10
															800			600		500		500					400		400		300		400	25	100
																						600		600	500					400			480	20 5/6	100
																																	500	2	10
																				600							500				400	300	500	20	100
																									600								576	17 13/36	100
																											600		600	500	500	400	600	16 2/3	100
																																	600	16 2/3	100
																								800									640	15 5/8	100
																														600			720	13 8/9	100
																																	750	1 1/3	10
																															600	500	750	13 1/3	100
																													800				800	12 1/2	100
																																	1000	1	10
																																600	1000	10	100

use as index $^1/_{10}$, $^1/_{100}$, etc. values which should be located in the above watthour constant values between 10 and 100 along with its corresponding register ratio which must be multiplied by 10, 100, etc. as the case may be.

Due to grouping two or more types of meters in one column, this table may include ampere sizes which were not manufactured in certain types of meters.

See Section No. 17 for Standard Dial Constants issued August, 1938, to meter manufacturers.

TABLE 14-H

CONSTANTS AND REGISTER RATIO DATA

FOR GENERAL ELECTRIC A-C WATTHOUR METERS LOG (DAILY) READING REGISTERS

Types			VOLTAGE (120 for the Range 100–120; 240 for 200–240; 480 for 400–480; and 600 for 500–600)																							
DS-2, DS-3, DS-4, DS-5	2 El. 25–30∼													120						240					480	600
	2 El. 40–50∼										120						240					480		600			
	2 El. 60∼							120						240					480		600						
DS-6, DS-7 (2 El. 25–60∼)						120						240					480		600							
DS-6, DS-7 (2 El. 25–60∼) 3 ph. 4 w. Y											120Y															
DS-9 (3 El. 25–60∼)											120Y															
DS-11, DS-12 (2 El. 25–30∼)												120					240					480		600		
DS-11, DS-12 (2½ El. 25–30∼) 3 ph. 4 w. Y															120Y											
DS-13 (3 El. 25–60∼)															120Y											
†DS-19, DS-21, DS-34, DS-38, DS-40 (2 El. 25–60∼)						120						240					480		600							
†DS-19, DS-21, DS-34, DS-38, DS-40 (2½ El. 25–60∼) 3ph. 4w. Y									120Y																	
†DS-20, DS-23, DS-35, DS-39, DS-41 (3 El. 25–60∼)									120Y																	
IS, IS-2, IS-3	1 El. 25–30∼						120						240													
	1 El. 40–50∼				120			240																		
	1 El. 60∼			120			240																			
IS-4, IS-5 (1 El. 25–60∼)			120			240																				
IS-6, IS-7 (1 El. 25–30∼)						120						240														
†IS-8, IS-9 (1 El. 25–60∼)			120			240																				
Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	AMPERE RATING																							
0.3	33 1/3	* 1	5	5																				
0.36	27 7/9	* 1																						
0.4	25	* 1			5																			
0.6	16 2/3	* 1	10	10		5	5																	
0.72	13 8/9	* 1																						
0.75	13 1/3	* 1			10			5																
0.9	11 1/9	* 1	15						5															
1	10	* 1		15						5	5													
1.08	9 7/27	* 1																						
1.2	8 1/3	* 1				10						5												
1.25	8	* 1			15		10						5											
1.44	6 17/18	* 1																						
1.5	6 2/3	* 1	25	25				10						5										
1.8	5 5/9	* 1				15			10															
2	5	* 1			25		15			10	10				5	5								
2.16	4 17/27	* 1																						
2.4	4 1/6	* 1										10					5							
2.5	4	* 1						15					10					5						
2.7	3 19/27	* 1							15															
2.88	3 17/36	* 1																						
3	3 1/3	* 1	50	50		25	25			15	15			10					5	5						
3.6	2 7/9	* 1										15												
4	2 1/2	* 1		75	50			25					15		10	10					5					
4.32	2 17/54	* 1																						
4.5	2 2/9	* 1	75						25															
4.8	2 1/12	* 1															10					5				
5	2	* 1			75					25	25			15				10					5			
5.04	1 62/63	* 1																						
5.4	1 23/27	* 1																						
5.76	1 53/72	* 1																						
6	1 2/3	* 1	100	100		50	50					25	25		15	15			10	10				5	5	
6.48	1 44/81	* 1																						
7.2	1 7/18	* 1															15									
7.5	1 1/3	* 1		150	100		75	50						25				15			10					5
8.64	1 17/108	* 1																						
9	1 1/9	* 1	150			75			50										15							
9.6	1 1/24	* 1																			10					
10	1	* 1			150			75		50	50				25	25				15			10			
10.08	9 58/63	1																						
10.5	9 11/21	1																						
10.8	9 7/27	1																						
11.25	8 8/9	1																						
11.52	8 49/72	1																						
12	8 1/3	1	200			100						50					25							10		
12.5	8	1		200			100			75			50					25			15				10	
12.6	7 59/63	1																						
12.96	7 58/81	1																						
13.5	7 11/27	1							75															
14.4	6 17/18	1																			15					
15	6 2/3	1			200		150	100			75		75	50					25	25			15			10
15.12	6 116/189	1																						
15.75	6 22/63	1																						
16	6 1/4	1																						
16.2	6 14/81	1																						
16.8	5 20/21	1																						

TABLE 14-H (Continued)—GENERAL ELECTRIC Constants and Register Ratio Data

Types		VOLTAGE (120 for the Range 100–120; 240 for 200–240; 480 for 400–480; and 600 for 500–600)																							
DS-2, DS-3, DS-4, DS-5	2 El. 25–30~												120						240					480	600
	2 El. 40–50~								120						240					480		600			
	2 El. 60~					120						240					480		600						
DS-6, DS-7 (2 El. 25–60~)					120						240					480		600							
DS-6, DS-7 (2 El. 25–60~) 3 ph. 4 w. Y										120Y															
DS-9 (3 El. 25–60~)										120Y															
DS-11, DS-12 (2 El. 25–30~)											120					240					480		600		
DS-11, DS-12 (2½ El. 25–30~) 3 ph. 4 w. Y														120Y											
DS-13 (3 El. 25–60~)														120Y											
†DS-19, DS-21, DS-34, DS-38, DS-40 (2 El. 25–60~)					120						240					480		600							
†DS-19, DS-21, DS-34, DS-38, DS-40 (2½ El. 25–60~) 3ph. 4w. Y								120Y																	
†DS-20, DS-23, DS-35, DS-39, DS-41 (3 El. 25–60~)								120Y																	
IS, IS-2, IS-3	1 El. 25–30~					120						240													
	1 El. 40–50~			120			240																		
	1 El. 60~		120			240																			
IS-4, IS-5 (1 El. 25–60~)		120			240																				
IS-6, IS-7 (1 El. 25–30~)					120						240														
†IS-8, IS-9 (1 El. 25–60~)		120			240																				

Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	AMPERE RATING																							
17.28	5 85/108	1																								
18	5 5/9	1	300			150			100			75												15		
18.9	5 55/189	1																								
19.2	5 5/24	1																								
20	5	1		300				150		100	100			75	50	50					25				15	
21	4 16/21	1																								
21.6	4 17/27	1																								
22.5	4 4/9	1																								
23.05	4 49/144	1																								
24	4 1/6	1	400			200						100					50					25				
25	4	1		400	300		200			150			100			75		50					25			15
25.2	3 61/63	1																								
25.92	3 139/162	1																								
27	3 19/27	1							150																	
28.8	3 17/36	1																								
30	3 1/3	1	500	500	400			200			150		150	100	75			75	50	50				25	25	
31.5	3 11/63	1																								
32	3 1/8	1																								
32.4	3 7/81	1																								
33.6	2 41/42	1																								
34.56	2 193/216	1																								
36	2 7/9	1	600			300			200			150					75									
37.5	2 2/3	1																								
37.8	2 122/189	1																								
38.4	2 29/48	1																								
40	2 1/2	1		600	500		300			200	200			150	100	100				75	50					25
40.5	2 38/81	1																								
42	2 8/21	1																								
43.2	2 17/54	1																								
45	2 2/9	1																75								
46.08	2 49/288	1																								
48	2 1/12	1				400						200					100					50				
50	2	1			600		400	300					200			150		100			75		50			
50.04	1 62/63	1																								
51.84	1 301/324	1																								
54	1 23/27	1							300																	
57.6	1 53/72	1																								
60	1 2/3	1				500	500	400		300	300			200	150			150	100	100			75	50	50	
63	1 37/63	1																								
64	1 9/16	1																								
64.8	1 44/81	1																								
67.2	1 41/84	1																								
67.5	1 13/27	1																								
69.12	1 193/432	1																								
72	1 7/18	1				600			400			300					150					75				
75	1 1/3	1					600	500		400			300			200				150	100				75	50
75.6	1 61/189	1																								
76.8	1 29/96	1																								
80	1 1/4	1									400				200											
81	1 19/81	1																								
84	1 4/21	1																								
86.4	1 17/108	1																								
90	1 1/9	1							500										150					75		
94.5	1 11/189	1																								
96	1 1/24	1										400					200					100				
100	1	1						600		500	500		400	300				200			150		100			75
108	9 7/27	10							600																	
120	8 1/3	10									600	500			300				200					100		
125	8	10								600			500	400		300				200			150		100	

TABLE 14-H (Continued)—GENERAL ELECTRIC Constants and Register Ratio Data

Types			VOLTAGE (120 for the Range 100-120; 240 for 200-240; 480 for 400-480; and 600 for 500-600)																							
DS-2, DS-3, DS-4, DS-5 2 El. 25-30∼													120						240					480	600
2 El. 40-50∼									120						240					480		600			
2 El. 60∼							120						240					480		600						
DS-6, DS-7 (2 El. 25-60∼)						120						240					480		600							
DS-6, DS-7 (3 El. 25-60∼) 3 ph. 4 w. Y											120Y															
DS-9 (3 El. 25-60∼)											120Y															
DS-11, DS-12 (2 El. 25-30∼)												120					240					480		600		
DS-11, DS-12 (2½ El. 25-30∼) 3 ph. 4 w. Y															120Y											
DS-13 (3 El. 25-60∼)															120Y											
†DS-19, DS-21, DS-34, DS-38, DS-40 (2 El. 25-60∼)						120						240					480		600							
†DS-19, DS-21, DS-34, DS-38, DS-40 (2½ El. 25-60∼) 3ph. 4w. Y									120Y																	
†DS-20, DS-23, DS-35, DS-39, DS-41 (3 El. 25-60∼)									120Y																	
IS, IS-2, IS-3 1 El. 25-30∼							120						240													
1 El. 40-50∼					120			240																		
1 El. 60∼				120			240																			
IS-4, IS-5 (1 El. 25-60∼)			120			240																				
IS-6, IS-7 (1 El. 25-30∼)						120						240														
†IS-8, IS-9 (1 El. 25-60∼)			120			240																				
Watthour Constant (K_h)	**Register Ratio (R_r)**	**Register Constant (K_r)**	AMPERE RATING																							
144	6 17/18	10										600					300					150				
150	6 2/3	10											600	500		400		300			200				150	100
160	6 1/4	10													400											
180	5 5/9	10																	300					150		
192	5 5/24	10															400					200				
200	5	10												600	500	500		400		300			200			150
240	4 1/6	10													600		500		400					200		
250	4	10														600		500		400	300				200	
288	3 17/36	10															600					300				
300	3 1/3	10																600	500	500	400		300			200
360	2 7/9	10																	600					300		
384	2 29/48	10																				400				
400	2 1/2	10																		600	500		400		300	
480	2 1/12	10																				500		400		
500	2	10																			600		500		400	300
576	1 53/72	10																				600				
600	1 2/3	10																					600	500	500	400
720	1 7/18	10																						600		
750	1 1/3	10																							600	500
1000	1	10																								600

R_g (Gear Ratio) = R_r (Register Ratio) × 100

In all cases the numerical value (disregarding the register constant) of 1 revolution of the 1st dial pointer is equal to 10, except where indicated by an asterisk (*), in which case the numerical value is equal to 1 (black dial).

† Applies only to 2.5 ampere meters for use with current transformers with 5 ampere secondary.

Refer to Table 14-J for Constants and Register Ratio Data for A-C watthour meters used with instrument transformers of other ratings than listed here. After determining the primary watthour constant from Table 14-J the first three columns of this table may be used to determine the constant and register ratio of the meter. If the primary watthour constant is higher than 100, use as index $^1/_{10}$, $^1/_{100}$, etc. values which should be located in the above watthour constant values between 10.08 and 100 along with its corresponding register ratio which must be multiplied by 10, 100, etc. as the case may be.

TABLE 14-I

CONSTANTS AND REGISTER RATIO DATA

FOR GENERAL ELECTRIC A-C WATTHOUR METERS BASED ON "RATIO OF GEARS"

Type	VOLTAGE (110 for the Range 100–110; 220 for 200–220; etc.)				
IP Form SR-2	...	...	110	220	550
IP Form DF-2	...	...	110	220	550
IF & IG Form SR-1 (2- and 3-Wire)	110	220	...	...	...
IF & IG Form DF-2 (2- and 3-Wire)	110	220	...	...	...

Watthour Constant (K_h)	Ratio of Gears**	Register Constant (K_r)	AMPERE RATING				
0.2	0.2	1	3	...	...	...	...
0.3	0.3	1	5	...	...	...	...
0.4	0.4	1	...	(a) 3	...	...	...
0.5	0.5	1	...	(b) 3.5	...	...	...
0.6	0.6	1	10	(a) 5	3	...	...
1	1	1	15	(b) 7.5	5	...	...
1.25	1.25	1	...	(a) 10	...	3	...
1.5	1.5	1	25	...	...	...	...
2	0.2	10	...	15	10	5	...
3	0.3	10	50	25	15	...	3
4	0.4	10	...	...	...	10	...
5	0.5	10	75	...	25	...	5
6	0.6	10	100	50	...	15	...
10	1	10	150	75	50	25	10
12.5	1.25	10	...	(a) 100	...	...	...
15	1.5	10	...	...	75	...	15
20	0.2	100	...	(a) 150	100	50	...
25	0.25	100	...	...	...	...	25
30	0.3	100	...	...	150	75	...
40	0.4	100	...	...	...	100	...
50	0.5	100	...	...	...	...	50
60	0.6	100	...	...	...	150	...
75	0.75	100	...	...	...	...	75
100	1	100	...	...	...	...	100
150	1.5	100	...	...	...	...	150

* These meters have registers for which 1 revolution of the 1st dial pointer (disregarding the register constant) is equal to 1000 watthours. This corresponds to a numerical value of 1 (kwhr) in later meters.

** Ratio of Gears equals the number of divisions passed over by the 1st dial pointer per revolution of the worm wheel, or, the fraction of a revolution of the 1st dial pointer per 10 revolutions of the worm wheel. This is not the Gear Ratio as defined in Section 9. The relation between Ratio of Gears and Register Ratio or Gear Ratio is as follows:

$$\text{Register Ratio } (R_r) = \frac{10}{\text{Ratio of Gears}}$$

$$\text{Gear Ratio } (R_g) = \frac{1000}{\text{Ratio of Gears}}$$

(a) 2-wire rating only. (b) 3-wire rating only.

TABLE 14-J

CONSTANTS AND REGISTER RATIO DATA FOR GENERAL ELECTRIC METERS USED WITH INSTRUMENT TRANSFORMERS

Determine from this Table the secondary watthour constant, and note the minimum register ratio (which for a 4-dial register will give at least 600 full-load hours).

Multiply the secondary watthour constant by the ratio of primary power to secondary power. For standard connections this ratio is the product of the C.T. and P.T. ratios. This gives the primary watthour constant.

With the primary watthour constant as index, refer to Table No. 14-G for 4-dial monthly reading registers, and to Table No. 14-H for log- or daily-reading registers.

Secondary Watthour Constant (Test Constant)
For Meters for Use with Instrument Transformers

Circuit	Types of Meters* Used with Instrument Transformers		Secondary Watthour Constant						Min. Register Ratio
			Voltage Range						
	Meter Rating 5 Amp	Meter Rating 2.5 Amp	100–120	121–140	200–240	241–280	400–480	500–600	
Single-phase.....	I-14, IS-4, -5	I-16, -20, -30, IS-8, -9	0.3	0.36	0.6	0.72	1.2	1.5	12
	I-15, IS-6, -7		0.6	0.72	1.2	1.44	2.4	3.0	6
3-wire, 3-phase 2-ph, 3, 4, or 5 w 4 w Δ, 3-ph	DS-6, -7, D-6, -7	D-14, V-3, V-6, V-8, DS-19, -21, -34, -38, -40	0.6	0.72	1.2	1.44	2.4	3.0	12
	D-8, DS-11, -12		1.2	1.44	2.4	2.88	4.8	6.0	6
4-wire Y, 3-phase	D-6, -7, DS-6, -7		1.0	1.2	2.0	2.4			12
	D-8, DS-11, -12		2.0	2.4	4.0	4.8			6
		D-14, V-5, DS-19, -21, -34, -38, -40	0.9	1.08	1.8	2.16			12
4-wire Y, 3-phase 4-wire Δ, 3-phase Totalizing	D-9, DS-9		1.0	1.2	2.0	2.4			12
	D-13, DS-13		2.0	2.4	4.0	4.8			6
		D-15, V-4, -9, -10, DS-20, -23, -35, -39, -41	0.9	1.08	1.8	2.16			12

* The addition of type letters M, R, or W, viz. IM-20, IR-20, IW-20, does not affect the data.

Example: Type D-14, 115 volts, 3-w, 3-ph, 400/5 amp, 2300/115 volts.
From Table above: Secondary Watthour Constant is 0.6.
Min Register Ratio is 12.
Primary Watthour Constant: 0.6 × 80/1 × 20/1 = 960.

4-dial Monthly Reading Register

	Watthour Constant	Register Ratio	Register Constant
From Table No. 14-G	96	$104\frac{1}{6}$	100
Answer:	960	$104\frac{1}{6}$	1000

Daily or Log Reading Register

	Watthour Constant	Register Ratio	Register Constant
From Table No. 14-H	96	$1\frac{1}{24}$	1
Answer:	960	$1\frac{1}{24}$	10

TABLE 14-K

DATA FOR TYPE M-20 GENERAL ELECTRIC DEMAND REGISTERS

Register Ratio	Full Scale Kw			Scale Nameplate Numbers		
	Class A	Class D	Class E	Class A	Class D	Class E
333 1/3	0.9	....	....	60325	.....	.....
277 7/9	1.05	0.77	....	60326	78697	.....
166 2/3	1.8	1.25	1.5	60330	60327	65266
138 8/9	2.15	1.5	1.8	60335	60328	60330
125	....	1.7	....	.....	60329	.....
119 1/21	....	1.8	....	.....	60330	.....
115 20/27	2.6	1.85	2.15	60342	60331	60335
111 1/9	2.7	1.9	2.2	60343	60332	60336
105 155/189	....	....	2.35	.....	.....	60338
104 1/6	2.8	2.0	....	60345	60333	.....
100	....	2.1	....	.....	60334	.....
99 13/63	....	2.15	2.5	.....	60335	60340
99 5/21	....	2.25	....	.....	60336	.....
92 16/27	3.1	2.3	2.7	60349	60337	60343
88 8/9	....	....	2.8	.....	.....	60344
86 29/36	3.4	2.45	....	60352	60339	.....
83 1/3	3.6	2.5	....	60353	60341	.....
79 26/63	....	2.7	3.1	.....	60343	60347
77 13/81	....	....	3.2	.....	.....	60349
74 2/27	4.0	....	3.3	60358	.....	60350
69 4/9	4.3	3.1	3.6	60361	60346	60353
66 2/3	4.5	3.2	....	60362	60348	.....
66 26/189	....	....	3.8	.....	.....	60355
63 31/63	....	....	3.9	.....	.....	60357
62 1/2	4.8	3.4	....	70517	60351	.....
61 59/81	....	....	4.0	.....	.....	60358
59 11/21	....	3.6	....	.....	60353	.....
57 47/54	5.2	3.7	4.3	60367	60354	60361
55 5/9	5.4	3.8	4.5	60369	60356	60362
52 172/189	....	....	4.7	.....	.....	60364
52 1/12	5.7	4.1	4.8	60371	60359	70517
50	....	4.3	....	.....	60360	.....
47 13/21	....	4.5	....	.....	60362	.....
46 8/27	6.5	4.6	5.4	60375	60363	60369
44 4/9	6.7	....	5.6	60376	.....	60670
43 29/72	....	4.9	....	.....	60365	.....
41 2/3	7.2	5.1	....	60378	60366	.....
40	....	5.3	....	.....	60368	.....
39 43/63	....	5.4	6.3	.....	60369	60374
38 47/81	....	....	6.5	.....	.....	60375
37 1/27	8.1	5.7	6.7	60382	60371	60376
34 13/18	8.6	6.1	7.2	60385	60372	60378
33 1/3	9.0	6.4	....	60386	60374	.....
31 47/63	....	....	7.8	.....	.....	60381
31 1/4	....	6.8	....	.....	60377	.....
30 70/81	....	....	8.1	.....	.....	60382
29 16/21	....	7.2	....	.....	60378	.....
28 101/108	....	7.4	8.6	.....	60379	60385
27 7/9	10.5	7.7	9.0	60393	60380	60386
26 86/189	....	....	9.4	.....	.....	60388
26 2/3	11.0	....	....	60394	.....	.....
26 1/24	....	8.2	....	.....	60383	.....
25	12.0	8.5	....	70516	60384	.....
24 56/81	....	....	10.0	.....	.....	60390
23 17/21	....	9.0	....	.....	60386	.....
23 4/27	13.0	9.2	10.5	60399	60387	60393
22 2/9	13.5	9.6	11.0	60400	60389	60394
20 5/6	14.0	10.0	12.0	60401	60391	70516
20	....	10.5	....	.....	60392	.....
19 53/63	....	10.5	12.5	.....	60393	60397
19 47/102	....	....	13.0	.....	.....	60399
18 14/27	16.0	11.5	13.5	60405	60395	60400
17 13/36	17.0	12.0	14.0	60407	60396	60401
16 2/3	18.0	12.5	15.0	60408	60398	70457
15 55/63	....	13.5	15.5	.....	60400	60403
15 35/81	....	....	16.0	.....	.....	60405
14 37/42	....	14.0	....	.....	60401	.....
14 22/27	....	....	16.5	.....	.....	60406
13 8/9	21	15.0	18.0	60414	60402	60408
13 1/3	22	16.0	....	60415	60404	.....
13 43/189	....	....	18.5	.....	.....	60410
12 28/81	....	....	20.0	.....	.....	60412
11 31/54	26	18.5	21	60419	60409	60414
11 1/9	27	19.0	22	60420	60411	60415
10 5/12	28	20.0	....	60421	60413	.....
9 7/27	32	23	27	60424	60416	60420
8 49/72	34	24	28	60426	60417	60421
8 1/3	36	25	....	60427	60418	.....
7 58/81	....	....	32	.....	.....	60424
7 11/27	....	....	33	.....	.....	60425
6 17/18	43	30	36	60432	60422	60427
6 2/3	45	32	....	60433	60423	.....
6 1/4	....	34	....	.....	62777	.....
6 14/81	....	....	40	.....	.....	60430
5 85/108	....	37	43	.....	60428	60432
5 5/9	54	38	45	60437	60429	60433
5 5/24	57	41	....	60439	60431	.....
4 17/27	65	46	54	60442	60434	60437
4 4/9	67	....	56	60443	.....	60438
4 49/144	....	49	....	.....	60435	.....
4 1/6	72	51	....	60444	60436	.....
3 139/162	....	....	65	.....	.....	60442
3 19/27	81	....	67	60446	.....	60443
3 17/36	86	61	72	60448	60440	60444
3 1/3	90	64	....	60449	60441	.....
3 7/81	....	....	81	.....	.....	60446
2 193/216	....	....	86	.....	.....	60448
2 7/9	105	77	90	60453	60445	60449
2 2/3	110	....	....	60454	.....	.....
2 29/48	....	82	....	.....	60447	.....
2 8/21	....	90	....	.....	60449	.....
2 17/54	130	92	105	60458	60450	60453
2 2/9	135	96	110	60459	60451	60454
2 1/12	140	100	....	60460	60452	.....
1 23/27	160	115	135	60464	60455	60459
1 53/72	170	120	140	60466	60456	60460
1 2/3	180	125	....	60467	60457	.....
1 37/63	....	....	155	.....	.....	60462
1 44/81	....	....	160	.....	.....	60464
1 13/27	....	....	165	.....	.....	60465
1 7/18	210	150	180	60469	60461	60467
1 1/3	220	160	....	60470	60463	.....
1 19/81	....	....	200	.....	.....	60468
1 1/9	....	....	220	.....	.....	60470
1 1/24	280	200	....	67833	62760	.....

Register Ratio	Class G (Full Scale Kw)	Class G (Scale Nameplate Numbers)
166 2/3	2.9	60345
83 1/3	5.7	60371
66 2/3	7.2	60378
33 1/3	14.0	60401

Class B registers have one-half the full scale values of Class A registers with the same register ratio. The demand scale for a Class B register of a given register ratio is, therefore, the demand scale which would be used on a Class A register with twice the register ratio. Example:

Class B register, register ratio $166^2/_3$ } N.P. 60325
Class A register, register ratio $333^1/_3$ }

TABLE 14-L

REVOLUTIONS OF REGISTER WORM WHEEL OF GENERAL ELECTRIC DEMAND REGISTER TYPE M-20 FOR FULL-SCALE (180 DEG.) DEFLECTION

Class	TIME INTERVAL		
	60 Minutes	30 Minutes	15 Minutes
A	30 $\left(\frac{30}{1}\right)$	15 $\left(\frac{15}{1}\right)$	$7\frac{1}{2}$ $\left(\frac{15}{2}\right)$
D	$21\frac{3}{7}$ $\left(\frac{150}{7}\right)$	$10\frac{5}{7}$ $\left(\frac{75}{7}\right)$	$5\frac{5}{14}$ $\left(\frac{75}{14}\right)$
E	25 $\left(\frac{25}{1}\right)$	$12\frac{1}{2}$ $\left(\frac{25}{2}\right)$	$6\frac{1}{4}$ $\left(\frac{25}{4}\right)$
B	15 $\left(\frac{15}{1}\right)$	$7\frac{1}{2}$ $\left(\frac{15}{2}\right)$	$3\frac{3}{4}$ $\left(\frac{15}{4}\right)$
G	.. ....	24 $\left(\frac{24}{1}\right)$	12 $\left(\frac{12}{1}\right)$

TABLE 14-N

DATA FOR TYPE M-31 GENERAL ELECTRIC DEMAND REGISTER

Register Ratio	FULL SCALE KW	
	Class 1	Class 2
333 1/3	0.5	1.0
166 2/3	1.0	2.0
138 8/9	1.2	2.4
111 1/9	1.5	3.0
104 1/6	1.6	3.2
92 16/27	1.8	3.6
83 1/3	2.0	4.0
69 4/9	2.4	4.8
66 2/3	2.5	5.0
55 5/9	3.0	6.0
52 1/12	3.2	6.0
46 8/27	3.6	7.0
41 2/3	4.0	8.0
34 13/18	4.8	9.5
33 1/3	5.0	10.0
27 7/9	6.0	12.0
20 5/6	8.0	16.0
18 14/27	9.0	18.0
16 2/3	10.0	20.0
13 8/9	12.0	24.0
10 5/12	16.0	32.0

TABLE 14-M

DATA FOR TYPE M-21 GENERAL ELECTRIC DEMAND METER

Register Ratio	Full Scale Kw	Scale NP No.	Register Ratio	Full Scale Kw	Scale NP No.
Registers with Rotating Cumulative-demand Disks					
STANDARD CLASS F					
333 1/3	1.0	60183	23 17/21	14.0	60151
277 7/9	1.2	60182	23 4/27	14.5	60150
166 2/3	2.0	60226	23 1/13	14.5	60150
138 8/9	2.4	60181	22 2/9	15.0	60149
125	2.6	60180	20 5/6	16.0	60228
115 15/19	2.9	60179	20	16.5	60148
115 20/27	2.9	60179	19 47/162	17.0	60147
111 1/9	3.0	60178	18 14/27	18.0	60229
104 1/6	3.2	60177	17 13/36	19.0	60146
100	3.3	60176	16 2/3	20.0	60224
92 16/27	3.6	60175	15 5/8	21.0	60145
86 29/36	3.8	60174	15 35/81	21.0	60145
86 16/19	3.8	60174	13 8/9	24.0	60230
83 1/3	4.0	60220	13 1/3	25.0	60144
77 13/81	4.3	60173	11 31/54	29.0	60143
74 2/27	4.5	60172	11 1/9	30.0	60231
69 4/9	4.8	60171	10 5/12	32.0	60142
69 3/13	4.8	60171	9 7/27	36.0	60141
66 2/3	5.0	60170	8 49/72	38.0	60140
62 1/2	5.0	60169	8 1/3	40.0	60225
61 59/81	5.0	60168	7 11/27	45.0	60139
57 47/54	5.5	60167	6 17/18	48.0	60138
55 5/9	6.0	60221	6 2/3	50.0	60137
52 1/12	6.0	60166	6 14/81	50.0	60136
50	6.5	60165	5 5/9	60.0	60135
46 8/27	7.0	60164	5 5/24	60.0	60134
46 2/13	7.0	60164	4 17/27	70.0	60133
44 4/9	7.5	60163	4 1/6	80.0	69132
43 29/72	7.5	60162	3 17/36	95.0	60131
41 2/3	8.0	60222	3 1/3	100.0	60130
40	8.0	60161	2 7/9	120.0	60129
38 47/81	8.5	60160			
37 1/27	9.0	60159			
34 13/18	9.5	60158			
33 1/3	10.0	60227	**CLASS G**		
31 1/4	10.5	60157			
30 70/81	10.5	60156			
28 101/108	11.5	60155	166 2/3	2.9	60179
27 7/9	12.0	60223	83 1/3	5.5	60167
26 2/3	12.5	60154	66 2/3	7.0	60164
26 1/24	12.5	60153	33 1/3	14.5	60150
25	13.0	60152			
Form P Registers with Rotating Cumulative-demand Pointers					
STANDARD CLASS F					
333 1/3	1.0	77312	26 1/24	12.5	80755
166 2/3	2.0	77311	23 4/27	14.5	78657
138 8/9	2.4	78719	23 1/3	14.5	78657
115 15/19	2.9	78654	20 5/6	16.0	77303
115 20/27	2.9	78654	18 14/27	18.0	77302
111 1/9	3.0	77310	16 2/3	20.0	77301
104 1/6	3.2	78718	13 8/9	24.0	77300
92 16/27	3.6	80759	13 1/3	25.0	80616
83 1/3	4.0	77309	11 1/9	30.0	77299
69 4/9	4.8	78717	8 1/3	40.0	77298
66 2/3	5.0	77308			
57 47/54	5.5	78655			
55 5/9	6.0	77307	**CLASS G**		
52 1/12	6.0	78716			
46 8/27	7.0	78656			
46 2/13.	7.0	78656	166 2/3	2.9	78654
41 2/3	8.0	77306	83 1/3	5.5	78655
34 13/18	9.5	80621	66 2/3	7.2	78656
33 1/3	10.0	77305	33 1/3	14.5	78657
27 7/9	12.0	77304			

SECTION 15

SANGAMO ELECTRIC COMPANY METERS

The following descriptive material relates to types of meters manufactured since 1924 by the Sangamo Electric Company. Information on other direct- and alternating-current types may be found in the appendix and previous editions of the *Electrical Metermen's Handbook.* Detailed data and constants, however, are included for all types.

Only salient features and major changes in meters are described. More detailed information concerning the meter types may be obtained from the manufacturer's published material.

MERCURY MOTOR METERS

Detailed information on mercury motor meters may be found in the appendix.

Type D-5 Watthour Meter

The Type D-5 direct-current watthour meters are furnished in two- and three-wire types. All meters above 10 amperes in rating operate from shunts which are internally connected for meters rated 75 amperes or less, and externally connected for those rated above that capacity.

Type D-5 Ampere-Hour Meter

The Type D-5 ampere-hour meter has the same general features as the Type D-5 watthour meter except that a permanent driving magnet is substituted for the electromagnet.

Type N Ampere-Hour Meter

The Type N meter is somewhat similar in construction to the Type D-5 ampere-hour meter.

ALTERNATING-CURRENT WATTHOUR METERS

Type HC Single-Phase Watthour Meter

In 1928 the Type H meter was compensated for both temperature and overloads, and the type designation was changed from H to HC. Fig. 15-1.

Base—The base is a grey iron casting, in which are located the potential and current electromagnets, each of which is removable and replaceable as a unit.

Grid—The grid supports the damping magnets, bearings and moving system.

Bearings and Moving Element—The moving element consists of an aluminum disk, carried on an aluminum hub and shaft.

The upper bearing screw carries a flexible upper pivot.

The lower bearing screw carries a sapphire cup jewel in which the lower pivot or ball rotates.

Permanent Magnets—The permanent magnets are made of chrome steel.

Adjustments—The full-load adjustment consists of a soft iron disk located directly beneath the poles of the permanent magnets. This shunts some of the damping flux, the amount depending upon its proximity to the poles.

The light-load adjustment consists of a vane located in the potential field gap, the position of which may be changed by a micrometer screw located just below and to the right of the full-load adjustment. The location of the vane in the field of the potential flux produces an unbalanced effect and tends to produce either forward or backward rotation.

The lag adjustment consists of an auxiliary winding on the tip of the potential electromagnet. This circuit is closed through a resistance.

Overload Compensation—The series yoke is fitted with an accurately dimensioned magnetic shunt held in a definite position between the pole faces by non-magnetic spacers. Saturation of this shunt increases the effective flux on overloads to keep the accuracy load curve flat to 300 per cent. Large

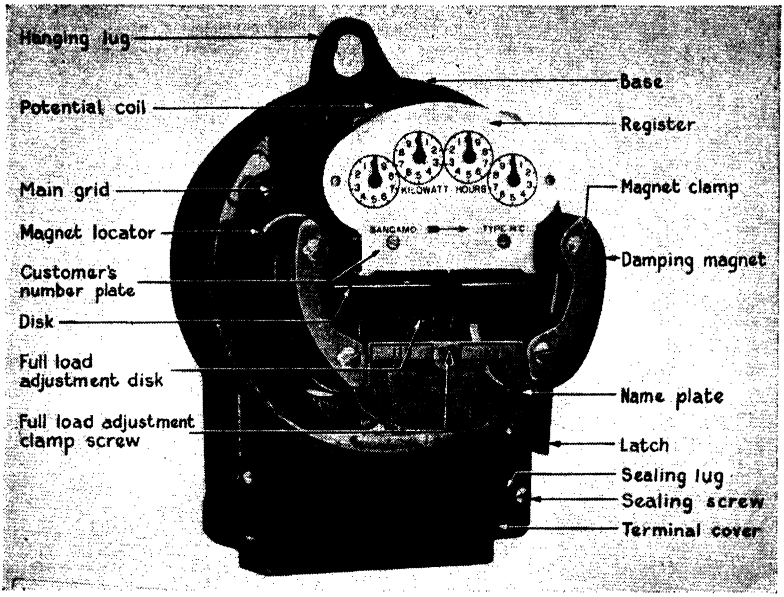


Fig. 15-1. Type HC Single-phase Watthour Meter

conductors in the current coil provide ample current-carrying capacity. Capacities up to and including 25 amperes will carry 300 to 400 per cent load continuously without serious temperature rise or effect on performance. Liberal overload rating also has been provided for the larger sizes.

Temperature Compensation — Type HC meters are compensated for the effects of temperature variation over a wide range. Compensation on noninductive load is achieved by the use of a thermal-responsive alloy for supports of the permanent magnets.

Temperature compensation on inductive loads is accomplished by employing an auxiliary lag plate, one leg of which is located in a slot in the tip of the potential electromagnet. The slot is closed by a wedge of thermal-responsive alloy.

Type HF Watthour Meter

The Type HF meters retain all the fundamental design characteristics of the Type HC meters. The major changes incorporated consist of an improved type of base, method of mounting the electromagnet, and the use of a 100-tooth worm-wheel register. The two- and three-wire, single-phase meters are made in four different types which are designated by the letters A, B, C, and S added to and following the HF type designation.

Type HFA Single-Phase Watthour Meter

Base, Cover, and Terminal Block—The base, which supports the electromagnet and the main grid, is made of aluminum alloy. The glass cover is interchangeable with covers used on A meters of other manufacture. The cover is of the studless type and is retained by three pins which fit into slots on the rim of the cover. The meter and terminal chamber covers are secured by a single seal or can be sealed separately. The terminal block is of molded bakelite and is interchangeable with blocks used in A meters of other manufacture. Fig. 15-2.

Main Grid—A cast-iron main grid supports the moving system, bearings, damping magnets, full- and light-load adjustments, and the register, assuring proper location of all parts with respect to each other. The entire grid assembly is removable as a unit.

Electromagnet—Fig. 15-2 illustrates the Type HF single-phase meter with cover removed. The potential and current electromagnets are the same as used in Type HC meters and are rigidly mounted on a steel grid. The return plate for the current flux is welded to the steel grid. The potential electromagnet is provided with brackets by which it is securely attached to the steel grid. This construction provides a complete electromagnet with all parts rigidly mounted in relation to one another, at the same time permitting the removal of either the current or potential electromagnet as an independent unit.

Meter Bearings—The upper bearing includes a removable phosphor-bronze ring which is mounted in the upper end of the disk shaft and rotates around the upper pivot. The upper pivot is integral with the upper bearing screw. Ample lubrication is assured by a reservoir in the end of the disk shaft just below the bearing sleeve. This reservoir is packed with pure white vaseline.

In these meters two forms of lower bearing systems have been used; in the early production of HF meters the pivot and jewel form only was used, but in later production the ball-bearing form is also supplied.

These complete bearing systems are interchangeable. Either type can also be used in Type HC meters.

In the pivot bearing, the upper end of the bearing screw is a split shell which holds the jewel assembly. This assembly consists of a nickeled cup in which the sapphire jewel is seated on a paper spacer and held in place by a retaining ring. In case of jewel replacement, only the jewel assembly itself need be replaced.

In the ball-bearing construction two jewels and a ball are used. The upper jewel is mounted in a retaining cup to which a pin is attached. When the pin is inserted into the end of the disk shaft, the upper jewel takes the place of the pivot used in the other construction.

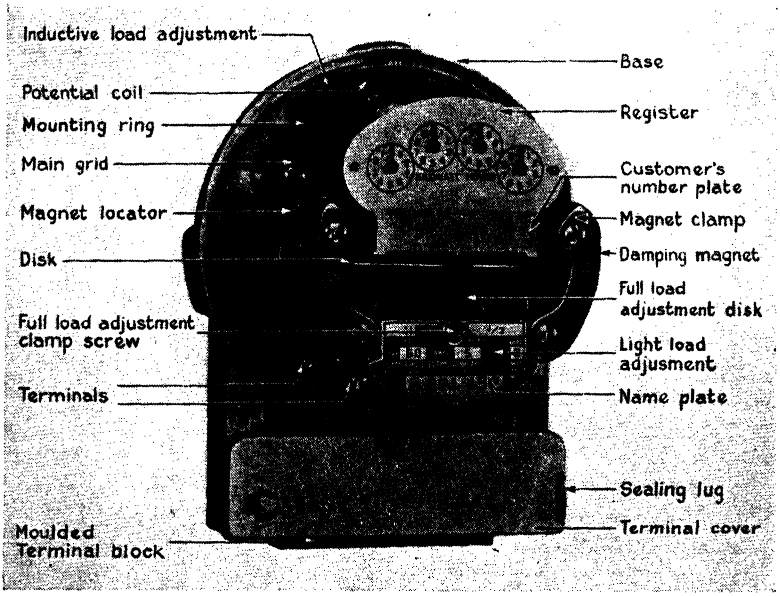


Fig. 15-2. Type HFA Single-phase Watthour Meter

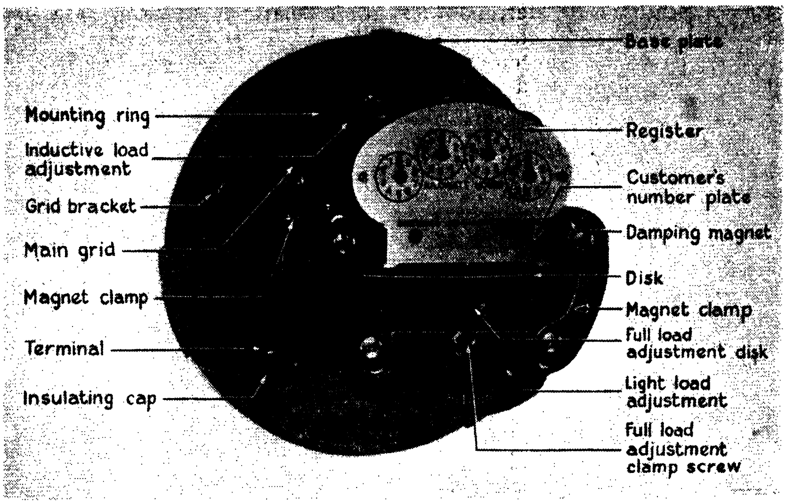


Fig. 15-3. Type HFS Single-phase Watthour Meter

The lower jewel is mounted in the lower bearing screw which is equipped with a shell surrounding both jewels. The ball is inserted between the two jewels.

Type HFB Single-Phase Watthour Meter

The Type HFB meter with disconnects incorporated in the terminal chamber differs from the HFA only in terminal construction. The B terminal block is interchangeable with the A block and consists of two molded bakelite pieces, the upper part carrying the disconnects and the lower part the regular line terminals. The block can be used to disconnect meters that are left installed though not in use. It provides a means of testing meters in place without interrupting the customer's service.

Type HFC Single-Phase Watthour Meter

The Type HFC meter not only includes disconnects similar to the B meter, but also provides an enclosure for all parts of the meter except the glass cover which extends through the cover of the enclosure.

The rear section of the enclosure is fitted with conduit connections at top and bottom for ¾″, 1″, or 1¼″ conduit. Near the bottom of the enclosure is mounted a terminal block very similar to the B line connection block. All line and load wires are brought to the terminal block and installed prior to setting the meter in place. When the meter is removed, the service may be sealed by a blank metal cover plate.

Type HFS Single-Phase Watthour Meter

The Type HFS meter is similar in all respects to the HFA meter except that it is of the socket type. The meter unit is listed separately as it may be used with a wide selection of sockets. This construction is readily adapted to either outdoor or indoor installations. Like other HF meters, all exposed parts are of weatherproof material or finish.

Sockets are available with from one to four threaded outlets for ¾″, 1″, and 1¼″ conduit or equivalent cable connection. They may be equipped with circuit-closing clips to facilitate removal of the meter without interruption of service.

When installed, the meter is held securely in place by a sealing ring. When the meter is removed, the service can be sealed by the use of a blank cover plate. Fig. 15-3.

Types JA and JS Single-Phase Watthour Meters

The Types JA and JS two- and three-wire alternating-current watthour meters supersede the Types HFA and HFS manufactured until 1940. Standard capacities are 5, 15, and 50 amperes in both two-wire and three-wire construction.

In design, these J meters are similar except that the JA meter is bottom-connected (Fig. 15-4), while the Type JS is of socket construction (Fig. 15-5). All those features which were of practical value have been retained, and the mechanical and electrical characteristics improved. The thermal capacity of the various current ratings has been increased, and the overload performance improved. Because of construction changes, the various parts of the J meter are not interchangeable with those of earlier design.

Base—The Type JA base is identical in over-all dimensions and mounting arrangements with that of the HFA; and the Type JS, with that of the HFS.

Cover—JA and JS covers are of glass and are interchangeable with those used on the Type HFA and HFS meters respectively.

Grid—The main grid (Fig. 15-6) is of cast iron and supports the moving system, register, and the damping magnets. The grid and its components are secured to the electromagnet by means of studs and nuts, thereby making it separable from the meter without disturbing the electrical circuits of the meter.

Electromagnet—The electromagnet is entirely new in form and dimensions. The current electromagnet dovetails into the potential electromagnet, thus forming a rigid unit and insuring proper alignment of parts and proper dimensions of air gaps. The two electromagnets are separable, and either

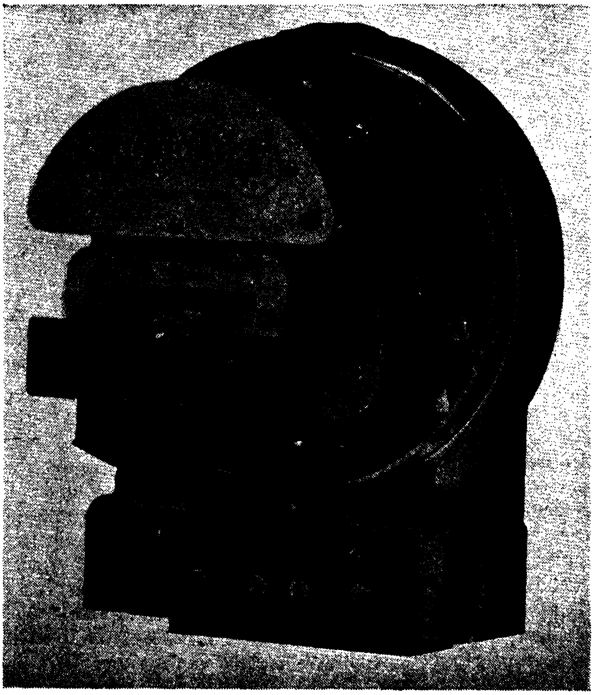


Fig. 15-4. Type JA Single-phase Watthour Meter

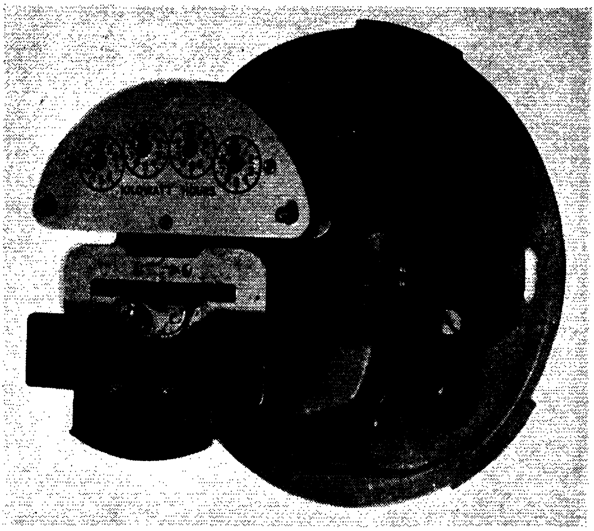


Fig. 15-5. Type JS Single-phase Watthour Meter

may be replaced without replacing the other.

Bearings and Moving System—The moving system of the Type J meter is illustrated in Fig. 15-6. An aluminum disk is secured to the aluminum spindle by means of a die-cast lead-antimony hub. The upper end of the spindle carries a worm for engaging the register worm wheel, and also an upper bearing sleeve. The lower bearing (Fig. 15-7), while not interchangeable with that used in the Type HF watthour meter, is a ball type of similar construction. A cobalt-tungsten ball is used, possessing unusual resistance to wear and corrosion, thereby requiring no lubrication and maintaining light-load accuracy over long periods.

The upper bearing (Fig. 15-8) is modified over earlier types. The sleeve which fits into the upper end of the meter disk shaft is the same and is interchangeable with the one used in the HF meter. The upper bearing screw and pivot is a new construction and not interchangeable. The pivot is relatively longer and more flexible, with the result that freedom from vibration and noise is secured without the use of lubricants. Both the upper and lower bearings, therefore, operate without oil and the meter is free from changes in registration attributed to the use of oil.

Damping Magnets — The damping magnet assembly is comprised of two U-shaped pieces of *Alnico* rigidly secured to a die-cast aluminum bracket by means of heavy aluminum clamps. Class I temperature compensation is also provided. Fig. 15-6.

Adjustments — Approximate full-load adjustment is obtained by varying the position of the magnet assembly on its support with respect to the center of the disk. Micrometer adjustment is obtained by means of a soft iron screw and magnetic shunt provided on the assembly. Adjustment range is approximately 4 per cent. The light-load adjustment is operated by a notched disk at the right side of the electromagnet and consists of a vane located in the potential field gap. Fig. 15-6. Lag adjustment is accomplished by changing the length of a resistance wire connected across an auxiliary winding on the current electromagnet. The lag adjustment is combined with the compensation for Class II temperature errors.

The 5-ampere, 120-volt, 60-cycle, two-wire J meter has a constant of 0.6

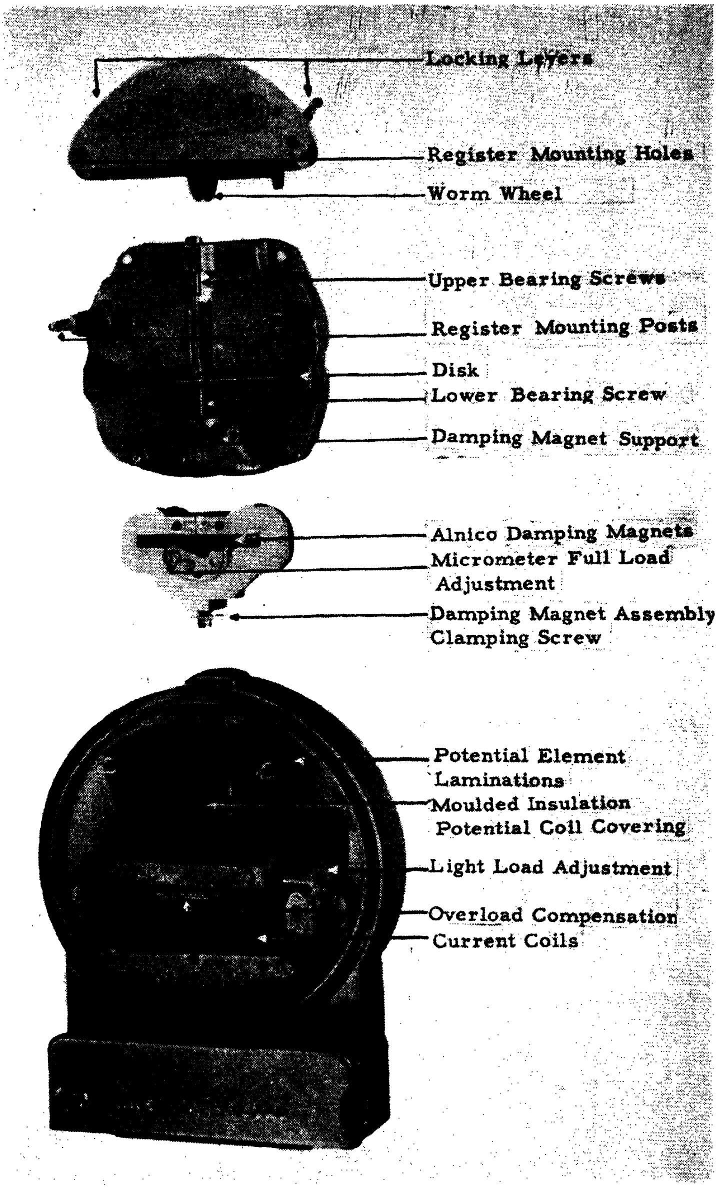


Fig. 15-6. Type JA Single-phase Watthour Meter (parts illustrated)

watthour per disk revolution with other capacities in proportion. The upper edge of the disk has been divided into 180 equal spaces and the peripheral edge of the disk carries 720 indentations. In addition, the disk is divided into 100 divisions for use with portable standard watthour meters when it is desirable to read to 1/100th revolution.

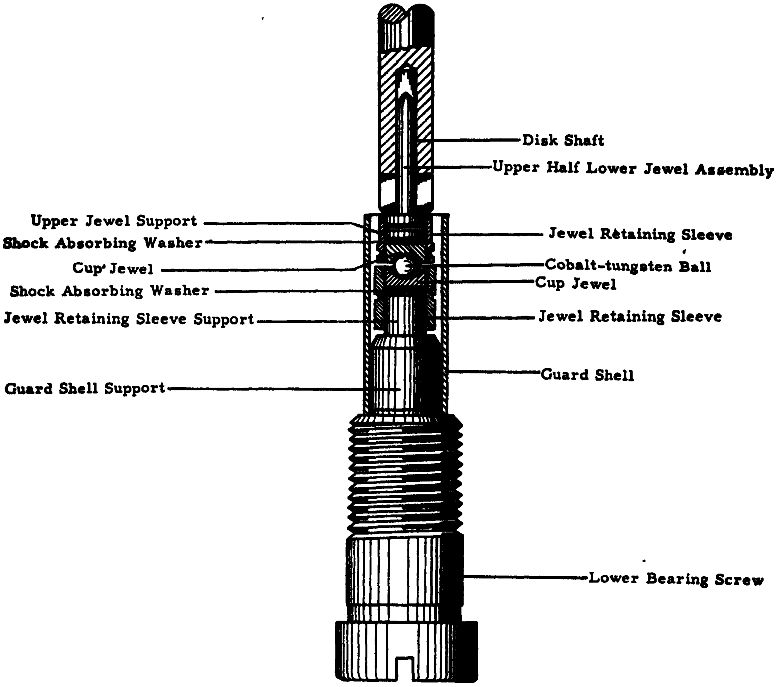


Fig. 15-7. Lower Bearing Assembly

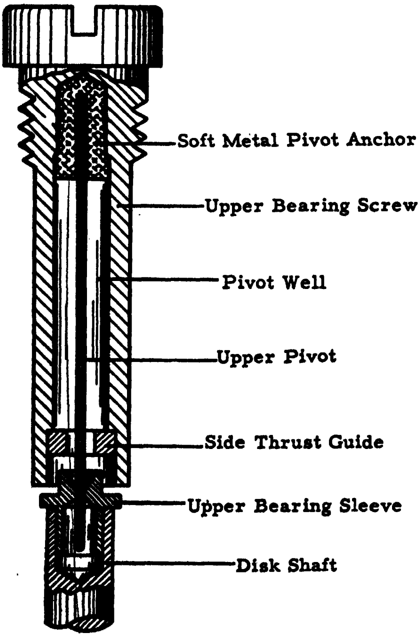


Fig. 15-8. Upper Bearing Assembly

POLYPHASE WATTHOUR METERS

Type HC Two-Element Polyphase Watthour Meter (Vertical Construction)

The two-element Type HC vertical polyphase meter consists of two single-phase meter elements arranged with their moving systems on a single shaft geared to a standard register. The meters are fully temperature-compensated and have the improved overload characteristics of the HC construction. They have potential indicating lamps, energized from the potential electromagnet. The arrangement of the current coils and the use of aluminum grids minimizes magnetic interference between elements.

Full-load, light-load and lag adjustments are the same as for the Type HC single-phase meter. The balancing of the torque of the two elements is easily effected by changing the position of the magnetic return plates

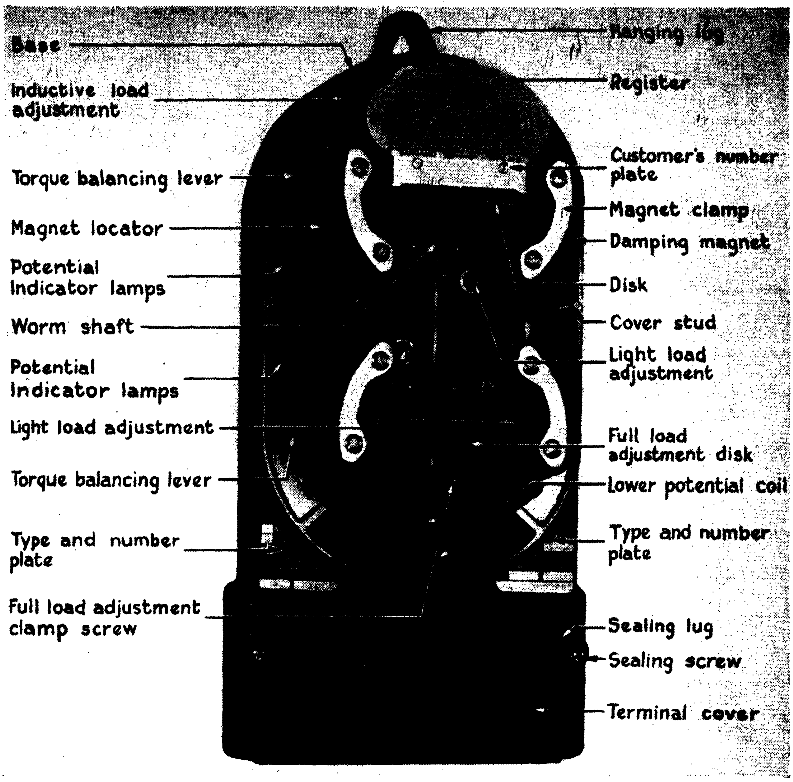


Fig. 15-9. Type HC Polyphase Watthour Meter

which are shifted by means of levers projecting from the sides of the grid. Fig. 15-9.

Type HC Two-Element Polyphase Watthour Meter (Horizontal Construction)

The horizontal polyphase meter combines two single-phase Type HC elements mounted side by side in a single base, the register being differentially geared to both elements.

Testing and adjustment of horizontal polyphase meter elements are the same as for Type HC single-phase meters. All parts except the cover, base and register are interchangeable with parts used in single-phase meters.

Type HC Three-Element Polyphase Meter

The three-element meter consists of three single-phase elements mounted in a single base with the three disks assembled on a single shaft. The upper bearing is the same as in all Type HC meters, but due to the additional weight of the moving element, a spring supported jewel is provided in the lower bearing.

Adjustments are the same as in the Type HC single-phase meter and are provided for each element. Torque balance between elements is the same as for two-element vertical type meters.

Type HC Switchboard Meter

Type HC meters in switchboard construction are furnished in round, rectangular or oval patterns.

Type HF Two-Element Polyphase Watthour Meter

Type HF two-element polyphase watthour meters are compensated to

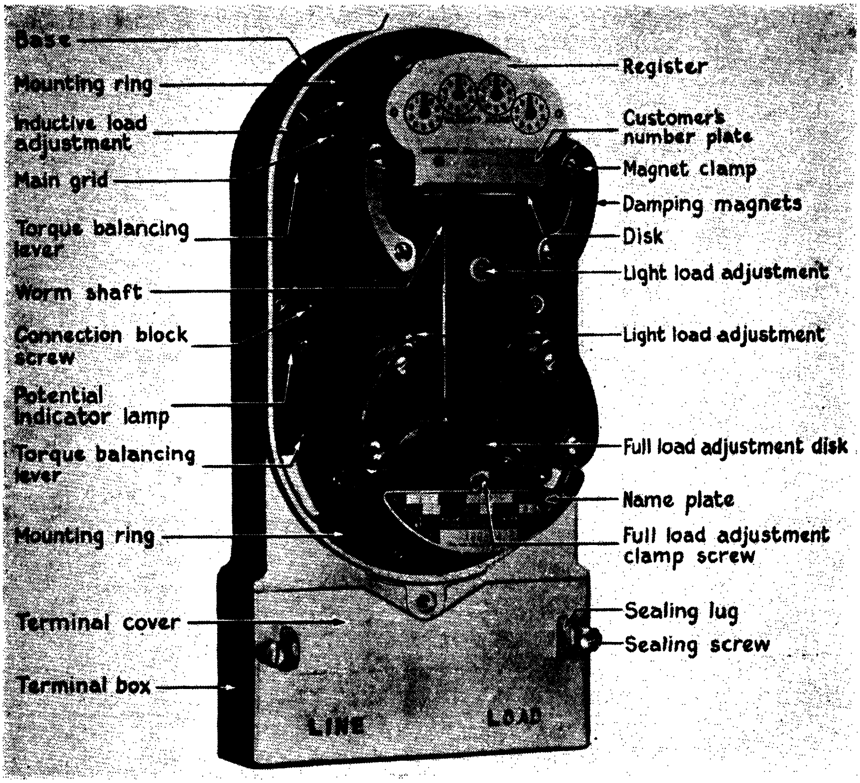


Fig. 15-10. Type HF Polyphase Watthour Meter

give a high degree of accuracy under variable load conditions, including unbalanced loads, as well as being temperature-compensated. Many of the parts are the same as used in HF single-phase meters. Fig. 15-10.

Base and Cover—The base is of cast aluminum and is provided with a beveled lug for interlocking with the cover ring. A sealing screw secures the cover and permits sealing the cover and terminal chamber under one seal, or separately. The meter terminal block is made in one piece of molded bakelite into which removable terminals are inserted.

Electromagnets — The electromagnets are comprised of separable potential and current coil assemblies which together with other component parts are mounted on steel grids to form complete and rigid units. They are provided with balancing adjustments and carry potential indicating lamps as an integral part of their assembly. The two elements are interchangeable.

Bearing System—The bearing system is identical with that used in HF single-phase watthour meters.

Main Grid—The main grid of aluminum carries the moving system, bearings, damping magnets, full- and light-load adjustments and the register. The entire grid assembly is removable as a unit.

Register—Type HF polyphase meters are provided with standard registers having 100-tooth worm wheels.

Type L-2 Two-Element, Single-Disk, Watthour Meter

The Type L-2 watthour meter is a two-element, single-disk, watthour me-

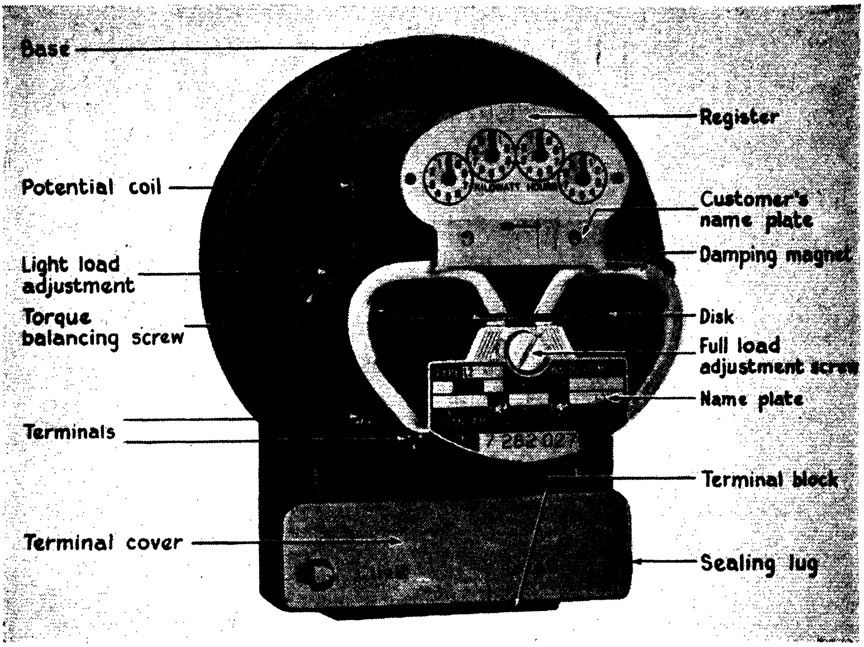


Fig. 15-11. Type L-2-A, Two-element, Single-disk, Watthour Meter

ter, L-2-A being the bottom-connected type, and L-2-S the socket type. These meters have two complete and separate driving elements acting upon a single disk. Figs. 15-11 and 15-12.

Bracket Assembly—A die-cast aluminum mounting bracket supports the entire meter structure. Any major part can be removed without affecting other units of the assembly.

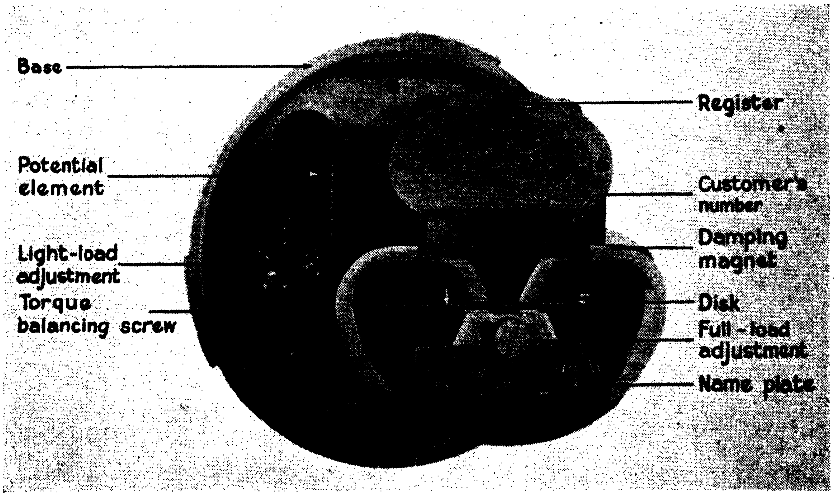


Fig. 15-12. Type L-2-S, Two-element, Single-disk, Watthour Meter

Electromagnets—The potential laminations are riveted to a pressed-steel frame to which the series coil laminations are dowelled and held by screws. This design facilitates separate removal of each coil assembly.

Accurate balancing of the two elements is accomplished through individual micrometer adjustments. The lag adjustment for each element is made by closing and soldering the leads of an auxiliary winding on the series coil yoke.

Permanent Magnets—The permanent magnets are mounted in a cast bronze clamp which also supports the auxiliary micrometer full-load adjustment.

Approximate full-load adjustment is obtained by varying the position of the permanent magnets with respect to the center of the disk. Micrometer full-load adjustment is obtained by turning a threaded soft iron core in the clamp between the lower tips of the magnets. A thermo-responsive alloy shunt compensates for temperature variations at unity power factor.

Bearing System—The bearing system is the same as used in the Type HF single-phase meters.

Register—The Type L-2 meters are provided with standard registers having 100-tooth worm wheels.

Type L-3 Three-Element, Single-Disk, Watthour Meter

The bottom-connected type of meter is designated as Type L-3-P, and the socket type is designated as Type L-3-S. These meters have three complete and separate driving elements acting upon a single disk. Except for the number of elements these meters are similar to the Type L-2 meters. Fig. 15-13.

Type LC-2, LC-2-A, LC-2½ and LC-3 Polyphase Watthour Meters

This LC line supersedes the L line of meters. Type designation is modified by the suffix P, A, or S to indicate the type of base. The essential modifications are:

1. A change in basic speed of the meter to that of the Type J single-phase watthour meter.
2. A change in the meter register.
3. The use of two Alnico magnets mounted in a manner similar to those used on the Type J watthour meter.

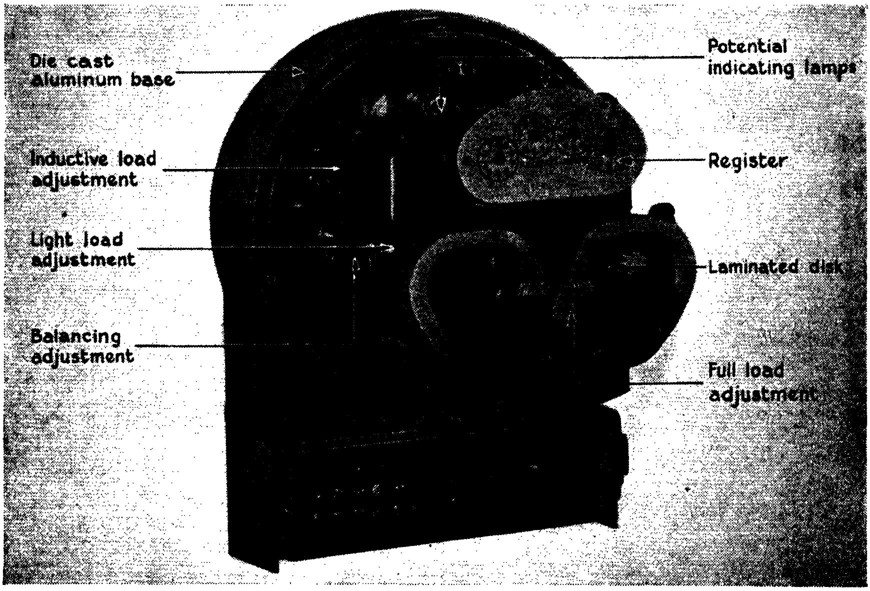


Fig. 15-18. Type L-3, Three-element, Single-disk, Watthour Meter

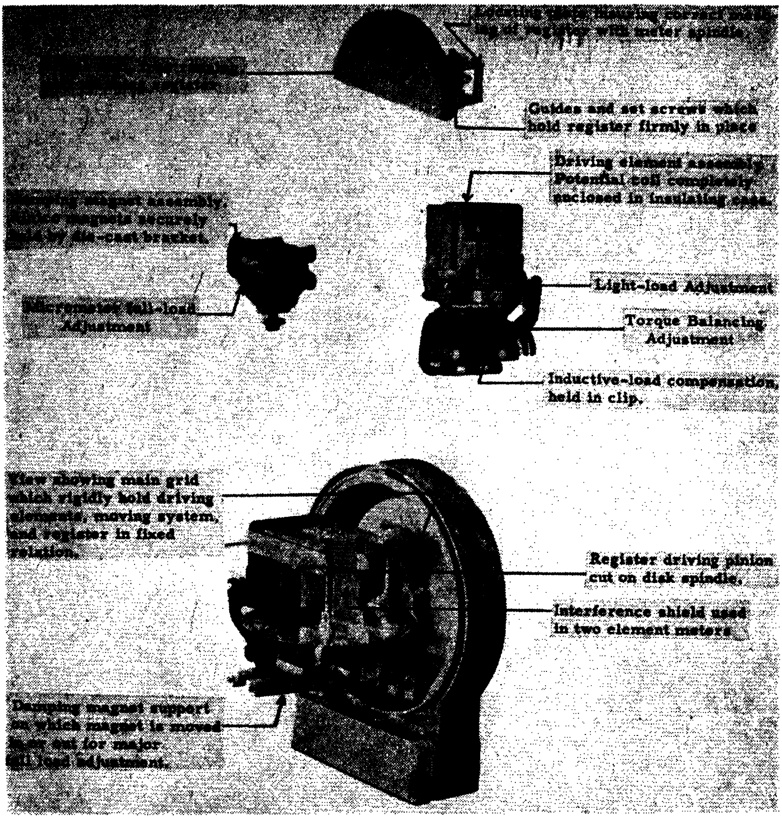

Locating plate insuring correct meshing of register with meter spindle.
Guides and set screws which hold register firmly in place
Driving element assembly. Potential coil completely enclosed in insulating case.
Damping magnet assembly. Alnico magnets securely held by die-cast bracket.
Micrometer full-load Adjustment
Light-load Adjustment
Torque Balancing Adjustment
Inductive-load compensation, held in clip.
View showing main grid which rigidly hold driving elements, moving system, and register in fixed relation.
Register driving pinion cut on disk spindle.
Interference shield used in two element meters
Damping magnet support on which magnet is moved in or out for major full-load adjustment.

Fig. 15-14. Type LC-2-A Watthour Meter (parts illustrated)

Type LC-2 meters in either the A, P, or S construction have the same dimensions as the corresponding Type L-2 meters. Type LC-3 meters, in general, have the same dimensions as Type LC-2, in either the P or S construction, except that the over-all height of the three-element meter is slightly greater than the corresponding heights of the LC-2 and LC-2-P meters. LC-2 and LC-3 covers are identical to and interchangeable with the corresponding Type L-2 and L-3 meter covers. Type LC bases in either the A, P, or S construction are identical with corresponding bases in the Type L construction. No change has been made in the Type LC mounting bracket in the two-element construction. In the three-element construction, provision is made for mounting the third element in the rear.

Moving Element and Bearings—The moving element of Type LC meters consists of an aluminum disk and hub, fastened to and adjustable with respect to the meter spindle, as in Type L-2 meters. In the upper end of the meter spindle, which is also made from aluminum alloy, is cut a nine-tooth pinion. Fig. 15-14. The lower end of the meter spindle carries a jewel which, together with a cobalt-tungsten ball and stationary jewel, forms the lower bearing of the meter. At the upper end of the spindle is a bearing sleeve identical with the corresponding part in Type L-2 and Type J meters. All bearing parts, including the upper pivot screw and lower bearing screw, are interchangeable with corresponding parts of Type J meters. Figs. 15-7 and 15-8.

The disk in the LC-2 two-element meter, Fig. 15-14, has a series of 21 radial slotted holes. This construction, in combination with a magnetic shield between elements, results in substantially complete freedom from interference between elements. In the three-element Type LC-3 watthour meter the elements are spaced at 90 degrees with respect to the meter spindle. Use is made of a laminated disk, which, in combination with magnetic shielding between elements effectively prevents interference between elements.

Register—The Type LC register (Fig. 15-14) differs from the register previously used on Type L watthour meters. The first reduction between meter spindle and register is accomplished by means of a pinion and gear, the pinion having 9 teeth and the gear 100 teeth. The first two gear reduction staffs are mounted vertically on sapphire jewel supports. Correct meshing is obtained by placing the register bracket in contact with the lower section of the upper bearing screw. The arrangement for mounting the register is shown in Fig. 15-14.

Adjustments—All adjustments except the full-load adjustment are identical with those used on Type L-2 meters. Full-load adjustments are identical with those of Type J meters with the exception that the permanent magnet assembly is so located with respect to the meter disk that moving the magnets toward the center of the meter decreases the meter speed instead of increasing the meter speed.

Electromagnets — The electromagnets of Type LC meters are identical with those of Type L-2 meters with minor exceptions. These exceptions consist of slight changes in the overload and voltage compensating bridges, which were made necessary by the lower full-

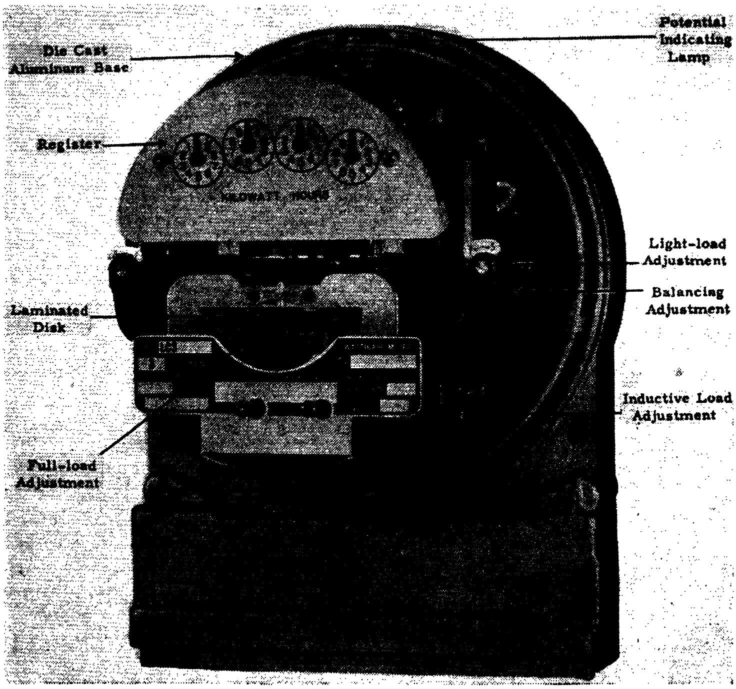


Fig. 15-15. Type LC-3-P Three-element, Polyphase Watthour Meter

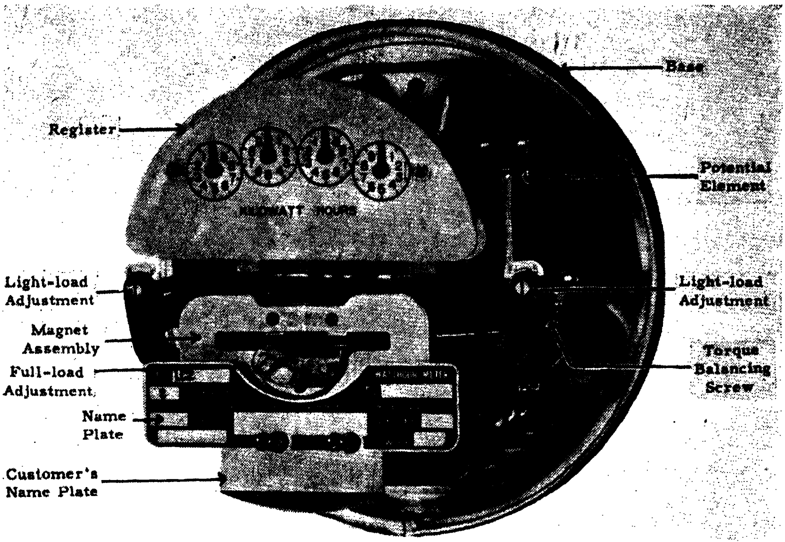


Fig. 15-16. Type LC-2-S, Two-element, Single-disk, Watthour Meter

load speed and the resulting decrease of compensation needed to produce favorable load and voltage characteristics. Fig. 15-15 is a partial side view of the LC-3-P watthour meter with cover removed, whereas Fig. 15-16 is a similar view of the Type LC-2-S.

DETAILED DATA AND CONSTANTS TABLES

Essential information concerning Sangamo meters has been compiled into the following reference tables:

Tables No. 15-A and 15-B contain detailed data.

Tables No. 15-C and 15-D list the constants for Sangamo amperehour meters.

Tables No. 15-E and 15-F list the constants and register data for Sangamo d-c and a-c meters.

PORTABLE STANDARD WATTHOUR METERS

Type HP-6 Portable Test Meter

The moving system and electrical circuits of this standard are essentially the same as used in Type H watthour meters except for modifications of the current and potential windings which are necessary to obtain the various required ranges of voltage and current.

The current coils are connected through a drum switch to provide 1, 5, 10, 25, 50, and 100 ampere ratings. The voltage ratings are 120, 240, 480, and 600 volts.

The register is of the three-pointer type and is provided with a zero reset. Figs. 15-17 and 15-18.

Type HP standards differ from the Type HP-6 in that the various coils are brought out to terminals instead of being selected by a rotary switch.

Type J-3 and J-5 Portable Test Meters

The magnetic circuits of these standards are similar to those employed in the Type J watthour meter.

The ratings of the current coils of the J-3 standard are 1, 5, and 25 amperes. The ratings of the J-5 current coils are 1, 5, 10, 25, and 50 amperes or 1, 5, 15, 25, and 50 amperes. The 15-ampere range is provided by the use of an internal compensating current transformer. Fig.

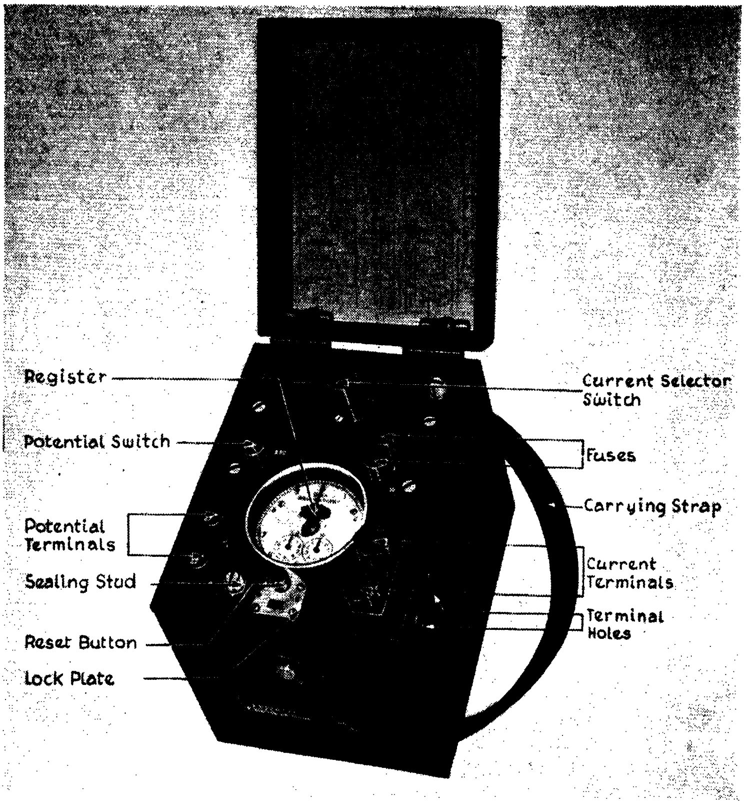


Fig. 15-17. Type HP-6 Portable Test Meter

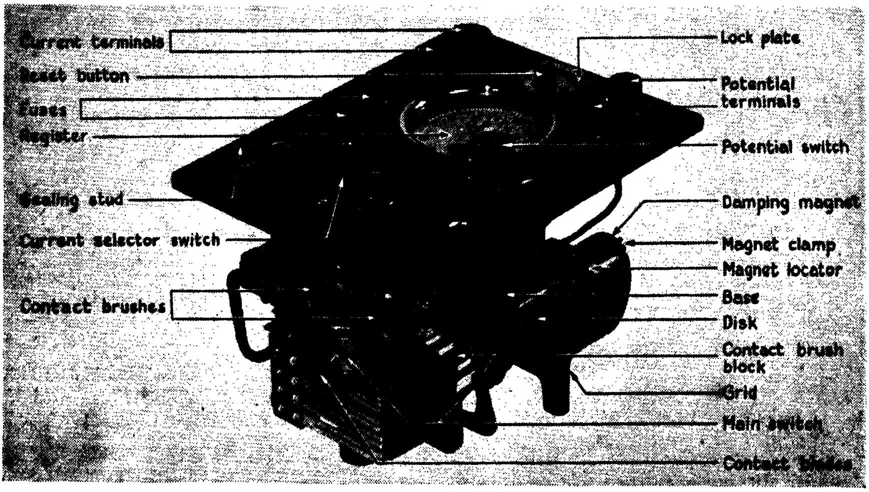


Fig. 15-18. Type HP-6 Portable Test Meter, internal view

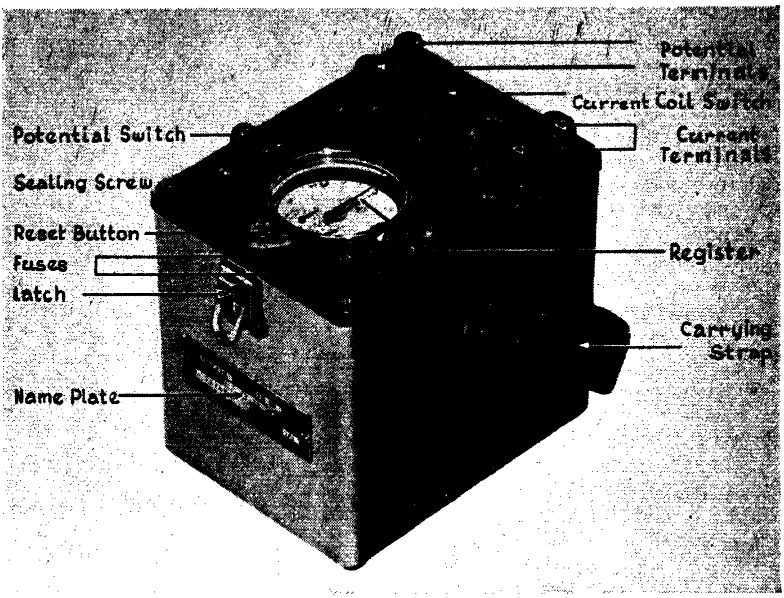


Fig. 15-19. Type J-5 Portable Test Meter

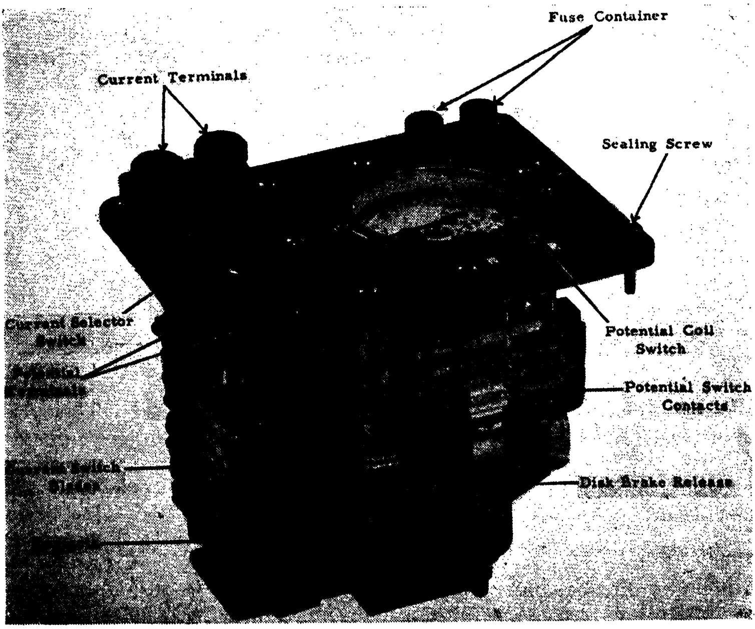


Fig. 15-20. Type J-5 Portable Test Meter, internal view

15-19 and Fig. 15-20. The case and cover are of aluminum. The entire structure of the standard is supported from a molded bakelite panel which rests on the upper edge of the standard case, a gasket being provided between the panel and case. The panel is secured to the case by means of four screws, one of which is sealable.

Independent temperature compensation is provided for both Class I and Class II temperature errors.

Damping magnets are of cast Alnico. Adjustments are similar to those of the Type J watthour meter.

A current coil selector switch employs silver contact buttons carried by phosphor-bronze blades and operates with a high contact pressure. The 50-ampere coil is capable of carrying 100 amperes continuously.

In Fig. 15-20 are shown details of the potential switch which is provided to permit the two sections of the potential coil to be connected in parallel or series for 120- or 240-volt operation. To prevent creeping, a braking device is provided. If it is desired to use the test meter without this brake, provision is made for locking it out of its operating position. Fig. 15-20.

The Type J standard has a full-load torque of 55 millimeter-grams and a potential loss at normal voltage of 1.1 watts.

Type J-33 Portable Test Meter

The Type J-33 portable test meter (Fig. 15-21) embodies the same electromagnet as that employed in the J-5 and differs only in the arrangement of the circuit selection features. The usual dial switch has been eliminated and the three current ranges are provided by means of binding posts mounted on the panel. These standards are nominally manufactured in capacities 1, 5, and 15 amperes and 120/240 volts.

Instrument Multipliers

Instrument multipliers are supplied for use on voltage in excess of 240 volts.

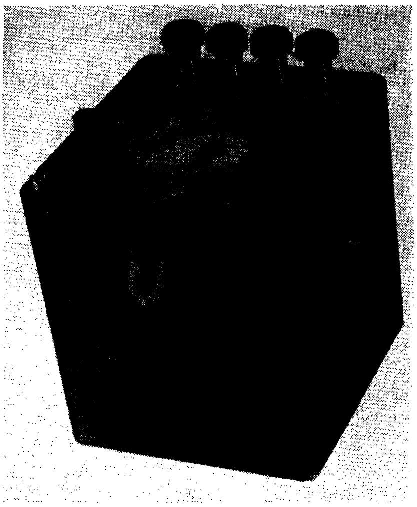


Fig. 15-21. Type J-33 Portable Test Meter

SPECIAL METERS

Time Switches

For measuring and controlling off-peak loads, meters and time switches as single units are supplied in a variety of combinations. These include the meter and time switches with contacts, meter with two-rate register and switch but without contacts, meter with two-rate register and time switch with contacts and, in addition, a meter with time switch and contacts employing a by-pass relay for remote control of off peak loads.

The Type HC meter combined with time switch was superseded by the Type HF in 1936. Fig. 15-22.

These combination units consist of a two-wire or three-wire watthour meter and either the Type VS synchronous motor or the Type VW electrically-wound time switches. The VW time switch will operate during current interruptions up to 20 hours. Both the VW and VS time switches are equipped with a device to omit the *off* operation on Sundays or other selected days so that unlimited service can be supplied on those days.

The minimum *on* time is 30 minutes, and minimum *off* time is 2½ hours.

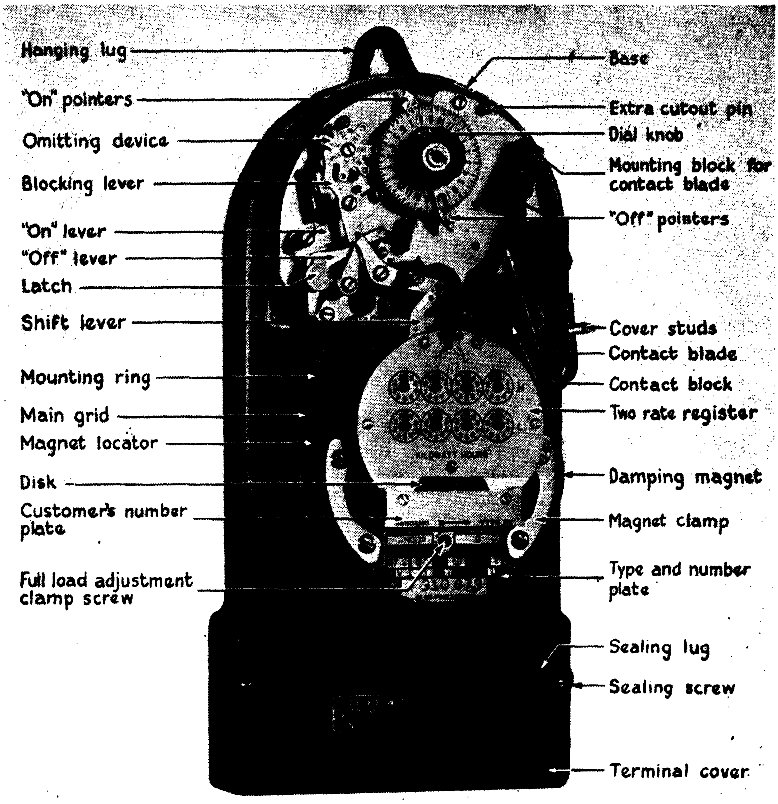


Fig. 15-22. Type HF Watthour Meter and Time Switch

Three *on* and *off* levers provide 1, 2, or 3 time periods.

Type HV Watthour Meter

The Type HV includes a Type HF single-phase watthour meter and a synchronous-motor time-switch mechanism combined with a meter register, and is built in either the A or S construction, for indoor or outdoor service. Fig. 15-23.

The time switch contacts are made of pure silver. A biasing spring, moving over dead center operates the contact mechanism. A similar biasing spring is used to hold the operating roller lever in position until the main operating biasing spring has been moved far enough to throw the contact either *off* or *on.*

The single-pole, single-throw contacts are rated at 30 amperes and the double-pole, single-throw at 20 amperes. Any of the combination units are supplied with either one or two *on* and *off* operations per day. The minimum time between successive operations is one and one-half hours. Manual operation will not affect the subsequent sequence of operation.

The register is supported in the same manner as the standard Type HF registers. In addition, the lower part is supported by the post which supports the full-load adjustment.

Type JV Watthour Meter

The Type JV watthour meter supersedes the Type HV. The general construction and principle of operation

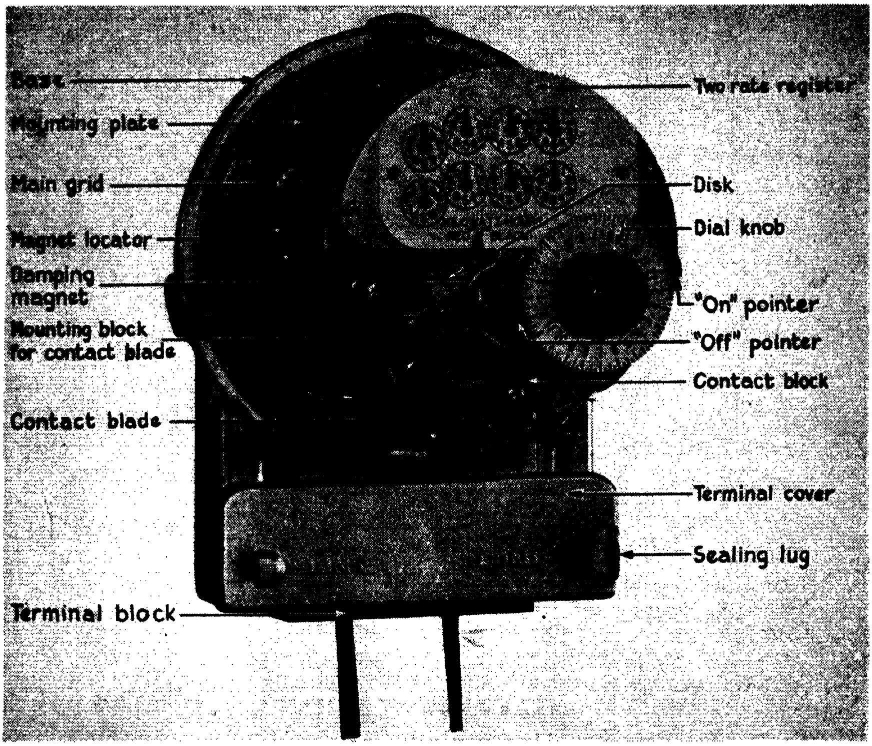


Fig. 15-23. Type HV Watthour Meter and Time Switch

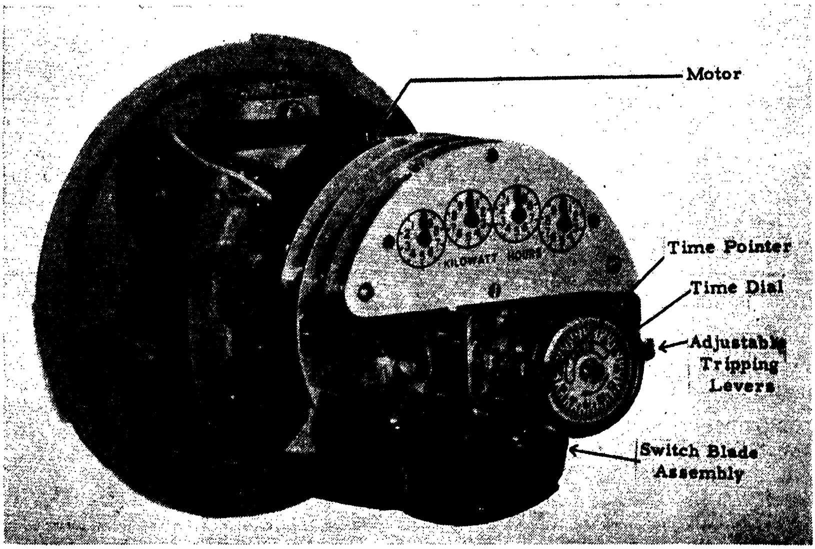


Fig. 15-24. JV-11-S Combination Meter and Time Switch

of the time switch is the same. Fig. 15-24.

Two-Rate Registers

All Sangamo Type H, HC, HF, J, L-2, L-3, and LC meters may be equipped with two-rate registers.

The two-rate register has two separate sets of totalizing dials with a change-over gear arrangement. The energy is thus recorded on one row of dials during certain selected hours of the day, and on the other row during the remainder of the day. These devices are manufactured in a variety of forms either as separate units or in combination with time-switch mechanisms. Fig. 15-25 is a view of the solenoid-operated two-rate register as applied to the Type J single-phase watthour meter. This register (Fig. 15-26) is actuated from time switch or other contacts external to the watthour meter. The two sets of register dials are geared to the meter spindle through the medium of a differential gear. The solenoid in turn actuates a rocker arm which is provided with spring claws that hold one side or the other of the differential gear, thereby permitting registration on each set of dials as desired. The rocker arm is further provided with an indicator extending over the dial face to indicate which set of dials is currently being actuated by the meter. The operations are so chosen as to record only on the low-rate register should a circuit failure occur.

When used in combination with self-contained time switches (Fig. 15-27), the time-switch operating mechanism is mechanically connected to a changeover gear lever so that when the time switch contacts are in the closed position, a small biasing weight is lifted and gears are put into mesh so as to register on the lower row of pointers. In all combination units, an opening with a sealable cap is located in the meter cover permitting the resetting of the time dial without removing the cover.

Setting of Time Dial and Tripping Levers—The time dial rotates in a counterclockwise direction. For resetting the tripping levers the small set screw is loosened, the lever moved to the desired position, and the screw

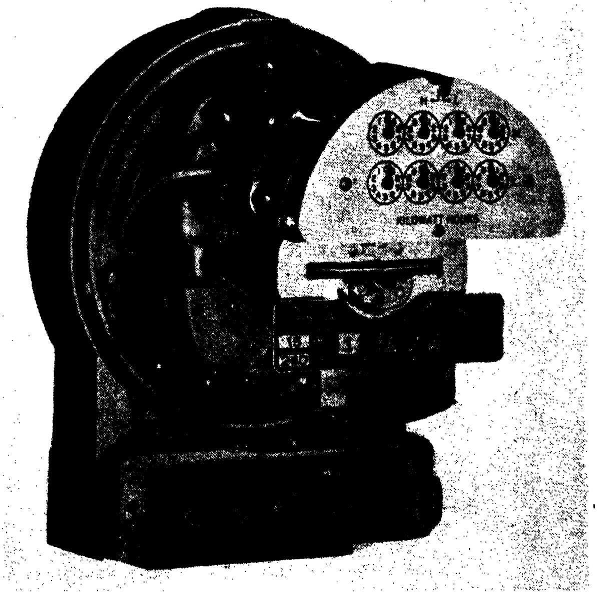


Fig. 15-25. JA Meter and Two-Rate Register

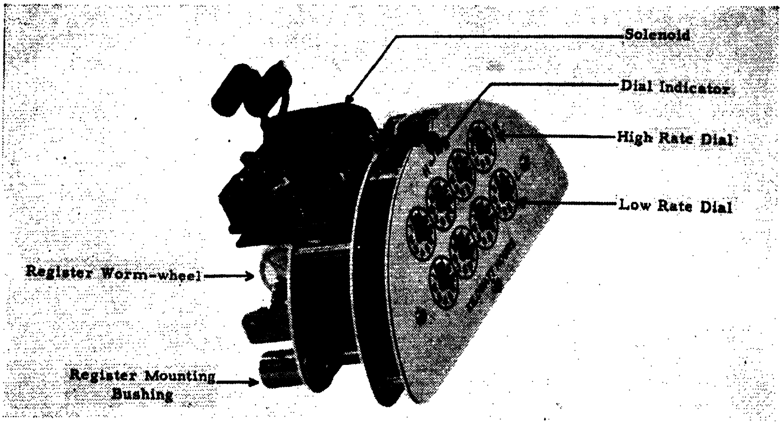


Fig. 15-26. Type J Two-Rate Register

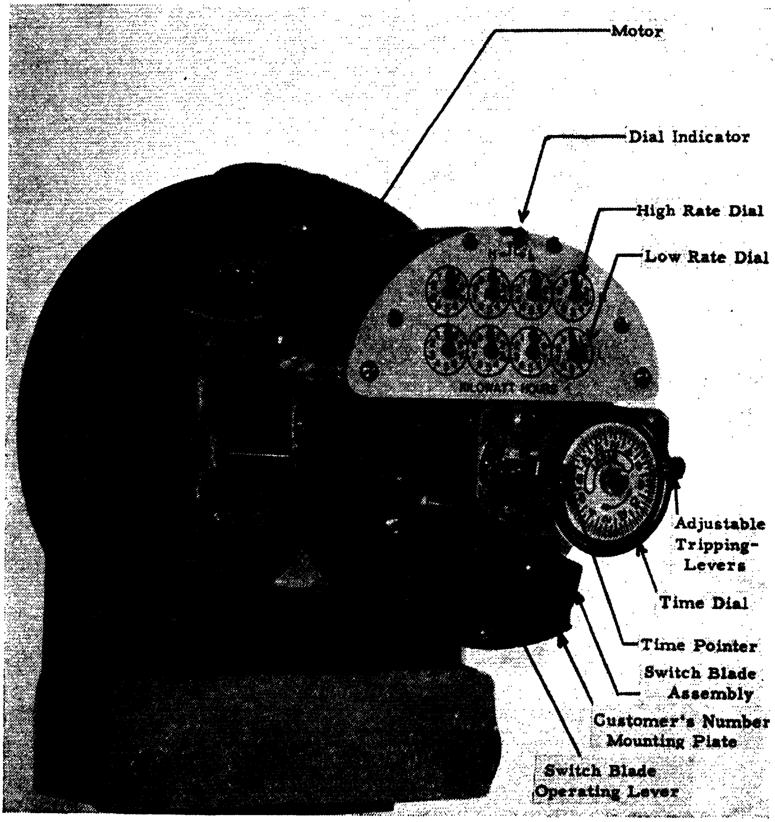


Fig. 15-27. Type JV-11 A2 Combination Meter, Time Switch and Two-Rate Register

again tightened. The time dial normally rotates in a counterclockwise direction, but it may be rotated in either direction. For accurate setting it should be rotated beyond the desired position and then moved in a clockwise direction to the correct time setting.

INDICATING DEMAND REGISTERS

Each of these devices is fundamentally a complete demand meter embodied in a watthour meter register for use on Sangamo a-c watthour meters. They are of the block-interval type, integrating and averaging the demand over a definite demand interval. Kilowatthour consumption is recorded by means of conventional dials and pointers. In registers of sweep-hand construction, the maximum kilowatt demand is indicated by a friction pointer and scale. In registers of the cumulative dial construction, the maximum demand for each demand interval is added to the cumulative reading by means of a set of dials and pointers.

Type HB Register

This demand register, Fig. 15-28, has a 300-degree scale and is of the block-interval type. The pointer pusher is returned to zero by means of a resetting spring operated by two cams revolving at different speeds and having segments cut out allowing a pin to drop when the openings in the cams come into coincidence at the end of each demand interval.

A manual reset with arrangement for sealing is mounted on the glass meter cover.

Standard demand intervals are 15 and 30 minutes.

Registers are supplied for 25 to 60 cycles, and 120 or 240 volts.

Type HG Register

This demand register supersedes the Type HB. It has been improved by the incorporation of a simplified interval selector and interval reset mechanism and is constructed for use with Type HF watthour meters. Figs. 15-29 and 15-30.

Type HGC Register

The Type HGC demand register (Figs. 15-31 and 15-32) is similar to the Type HG register, but is of the cumulative type.

Type JG Register

The Type JG demand register, Fig.

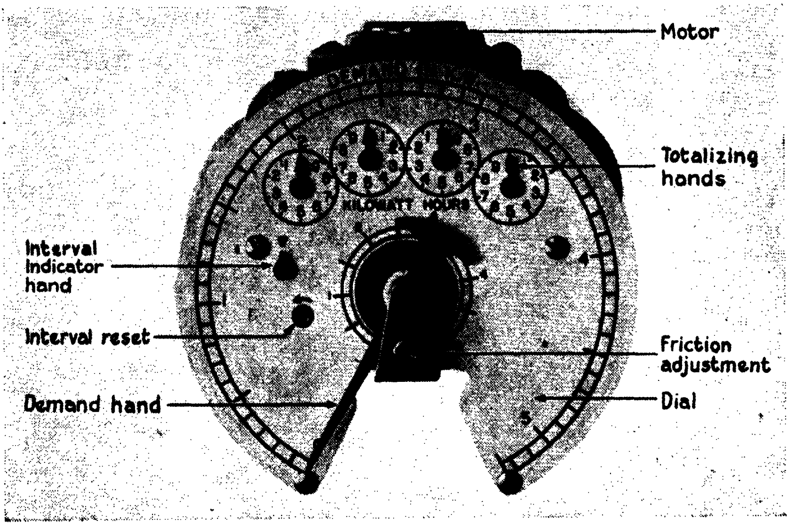


Fig. 15-28. Type HB Demand Register

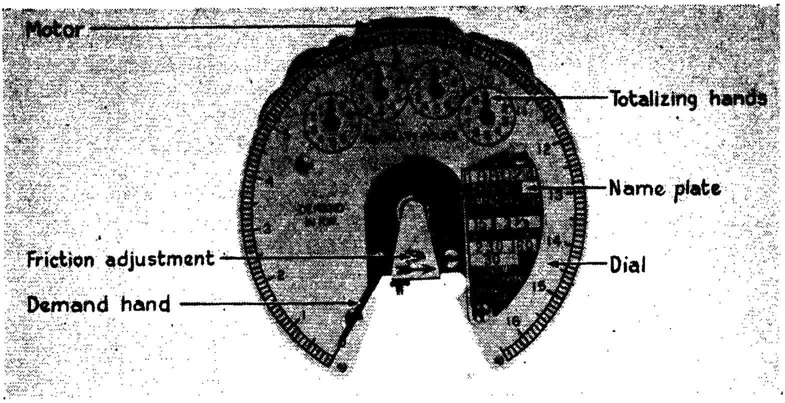


Fig. 15-29. HG Demand Register

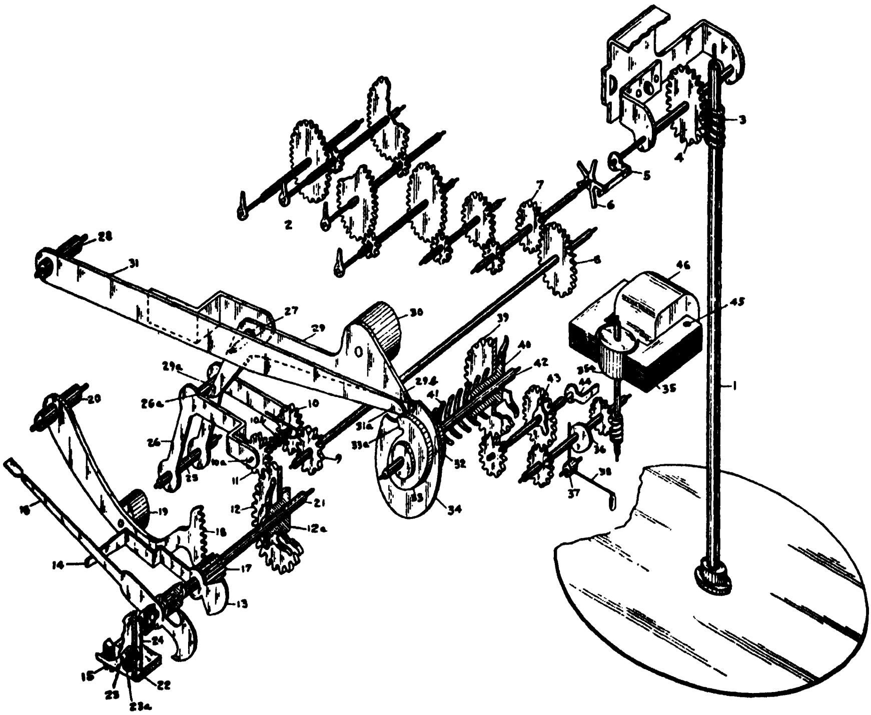


Fig. 15-30. HG Demand Register—Schematic Diagram

15-33, supersedes the Type HG and is used on all Type J single-phase meters. It retains all the features employed in the HG register. It is interchangeable with the normal meter register and is supplied in standard ratings and demand intervals. The timing motor is of improved construction, operating at a speed of 600 rpm on a 60-cycle supply. The exciting coil is inclosed in a molded shell and is replaceable. It is provided with plug-type terminals

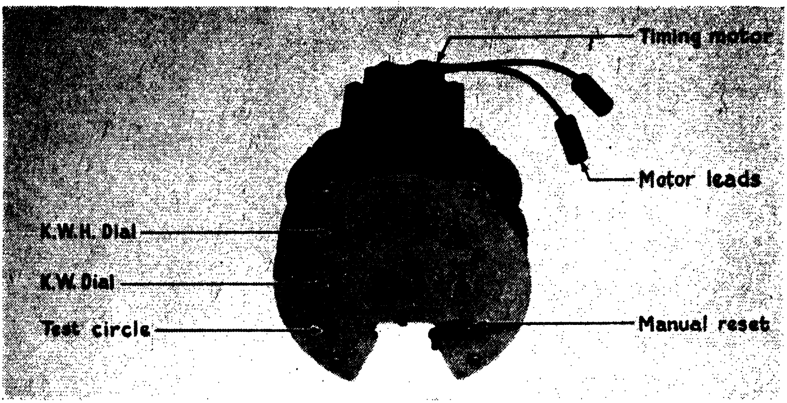


Fig. 15-31. HGC Demand Register

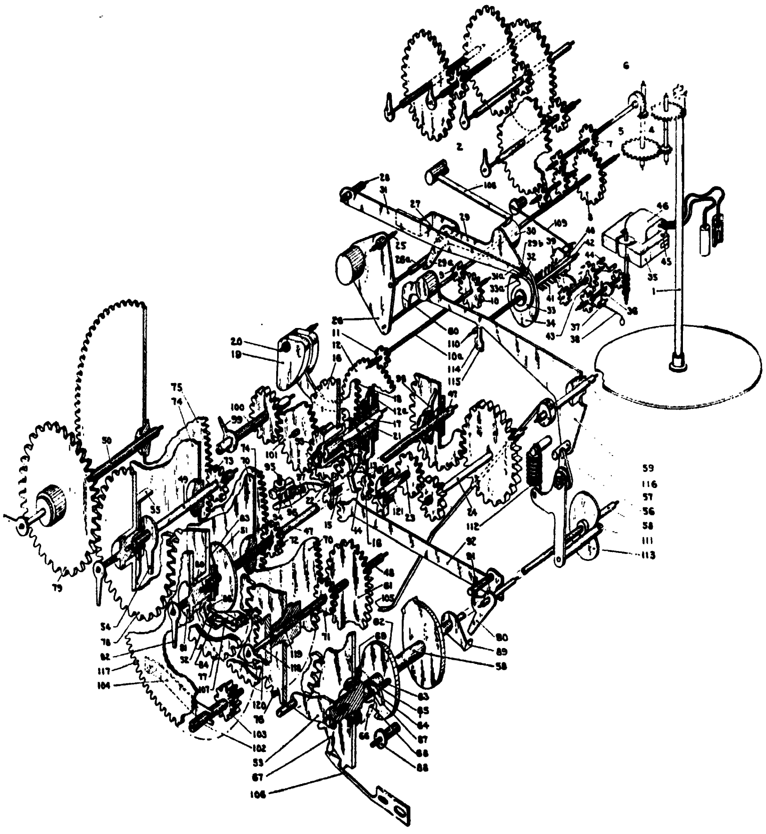


Fig. 15-32. HGC Demand Register—Schematic Diagram

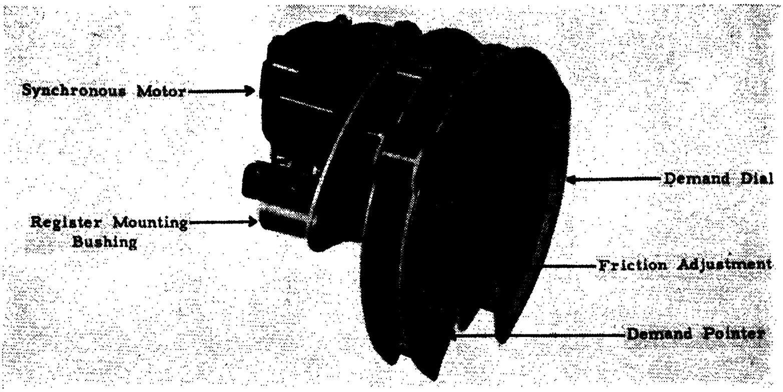


Fig. 15-33. JG Demand Register

for ease in connecting and disconnecting. The motor frame carries the bakelite first reduction, which is a gear and pinion arrangement rather than the worm and worm wheel previously employed. There are two adjustments, one to set the zero position of the pointer pusher and sweephand, and the other to adjust pointer friction. The interval timing mechanism may be reset to starting position by turning the timing cam in a clockwise direction until the pointer pusher returns to zero. Fig. 15-34.

The demand interval is determined by a synchronous motor which controls the speed of two cams. At the end of the interval, the pointer pusher shaft is disengaged due to the action of the dual cams, allowing the pointer pusher to return to zero through gravity action.

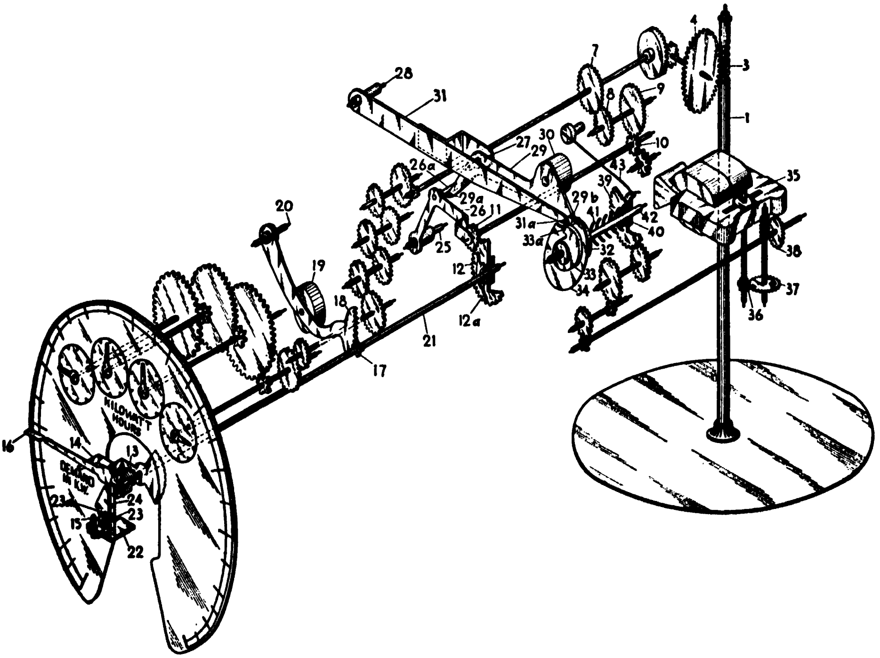


Fig. 15-34. JG Demand Register—Schematic Diagram

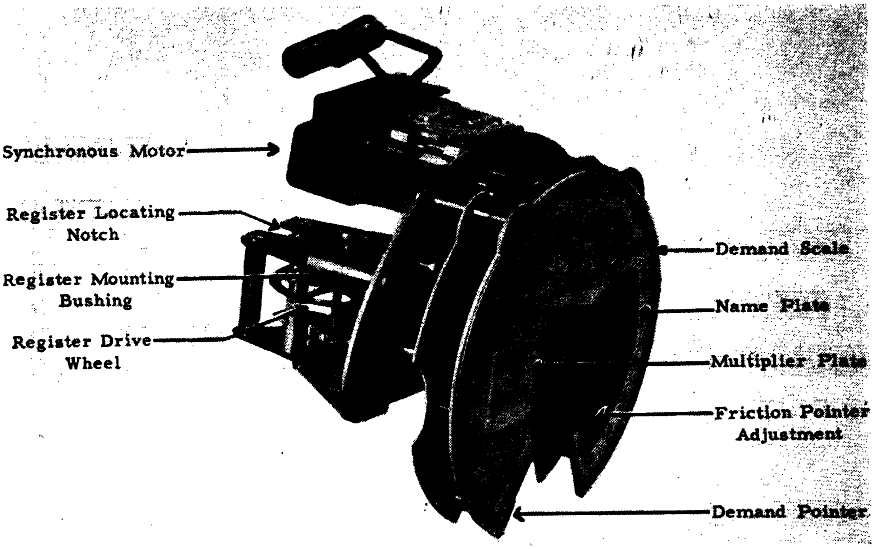


Fig. 15-35. Type LG Demand Register

Type LG Register

The Type LG demand register, Fig. 15-35, is similar to the JG in operating principle and mechanism, but is for use with Type LC polyphase watthour meters. The speed of the motor on 60-cycle registers is 1200 rpm.

Type LCGC Register

The Type LCGC demand register, Figs. 15-36 and 15-37, is similar to the Type LG register, but is of the cumulative type. It differs in the following respects:

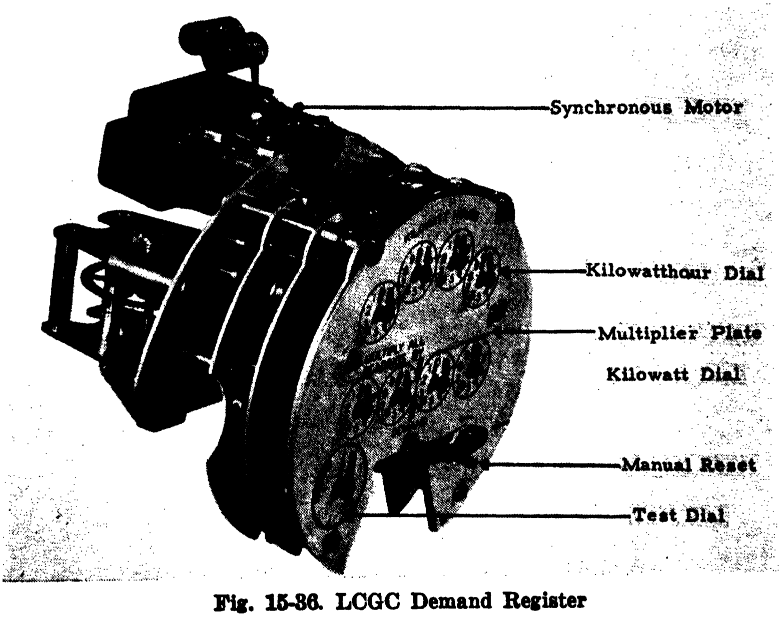


Fig. 15-36. LCGC Demand Register

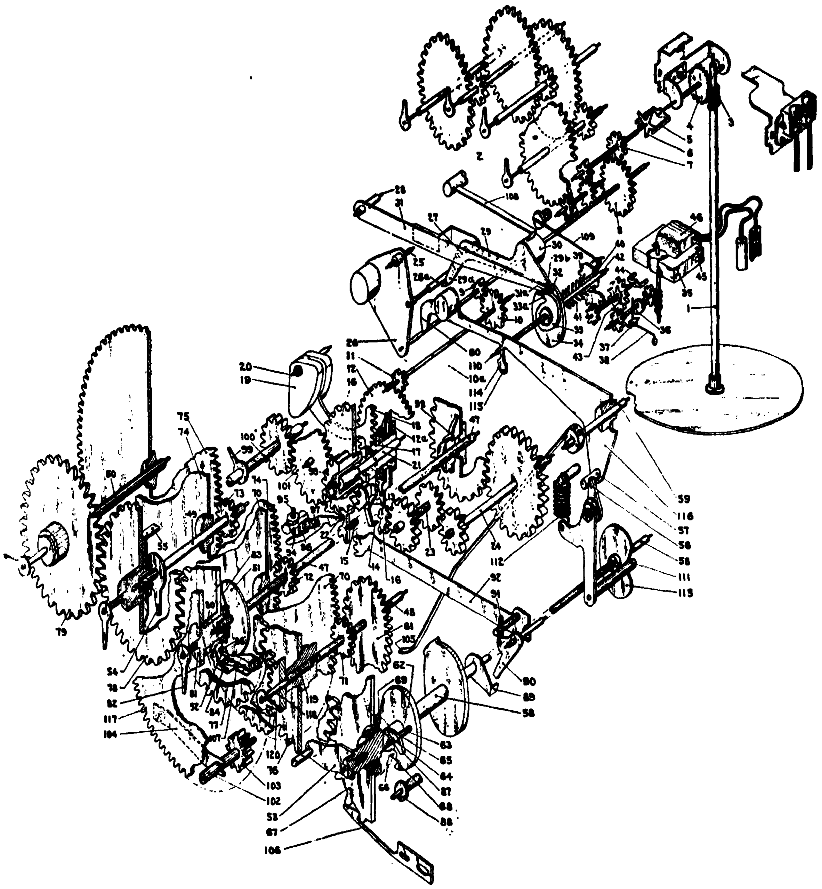


Fig. 15-37. LCGC Demand Register—Schematic Diagram

1. Four dials and pointers replace the sweep-hand maximum demand indicator.
2. Additional gearing is incorporated for the demand dials.
3. A manual resetting device is provided to advance the dial pointers to a position determined by the new maximum demand on performance of the manual operation.
4. A test dial has been added for the convenience of the tester and to indicate by application of a multiplier the maximum demand since the last reset.
5. The glass covers required are deeper, and the reset is provided with a ratchet to insure forward rotation to the sealing position.
6. Adjustments are provided for backlash compensation and monthly reset sector adjustment.

CONTACT-OPERATED INDICATING DEMAND METERS

These demand meters are used in conjunction with a watthour meter equipped with a contact device to indicate the maximum kilowatt demand by means of a friction pointer and scale. They are of the block-interval type, integrating and averaging the demand over a definite interval.

Form G Demand Meter

Form G demand meters were made in Types G-3, G-32, G-3A, and G-32A. Fig. 15-38.

Types G-3 and G-32 are for use on direct current to totalize the demand of two, three, or four watthour meters. The timing device consists of a spring-wound clock movement wound by means of a small d-c motor. Types G-3A and G-32A are similar to the G-3 and G-32, but are for use on alternating current. The timing device consists of a synchronous motor. Standard demand intervals are 15 and 30 minutes.

Type AG Demand Meter

Type AG demand meters supersede the Form G meters. Fig. 15-39.

The Type AG-3 is for use on direct current for indicating the maximum demand of one circuit only. It is operated by two-wire contacts.

The Type AG-32 demand meter is for use on direct current for indicating the total maximum demand on two, three, or four watthour meters, and differs from the AG-3 demand meter only in that it utilizes a two-coil solenoid. When the demand on two circuits is to be measured, the watthour meters are equipped with two-wire contacts; for three circuits, two of the watthour meters are equipped with three-wire quick-acting contacts, and the other watthour meter with two-wire contacts; and when four circuits are involved, all four watthour meters are equipped with three-wire quick-acting contacts.

The AG-4 demand meter differs from the AG-3 in that two solenoids are used. A contact on one side of a three-wire device functions to index the meter, while the other contact resets the mechanism.

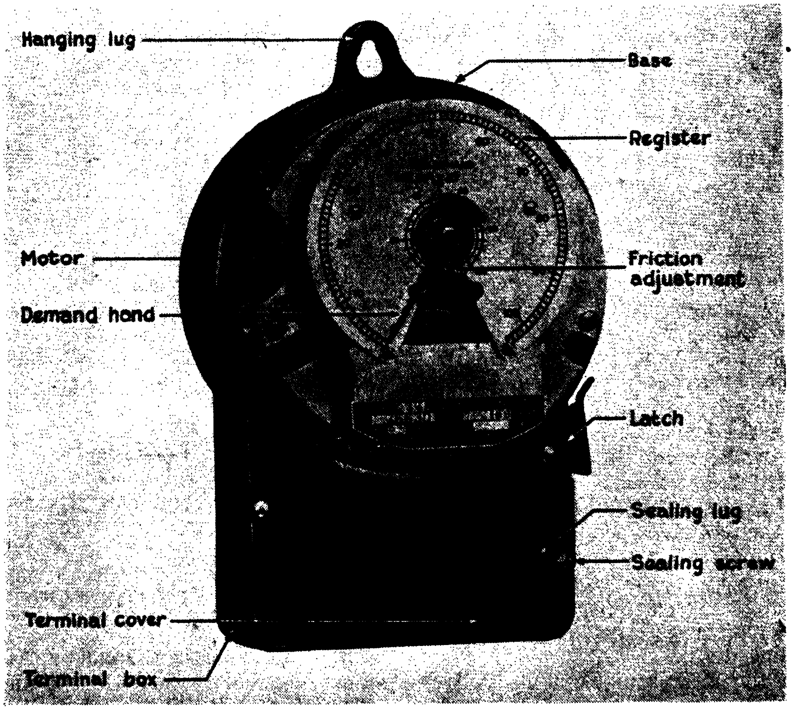


Fig. 15-38. Type G-32A Demand Meter

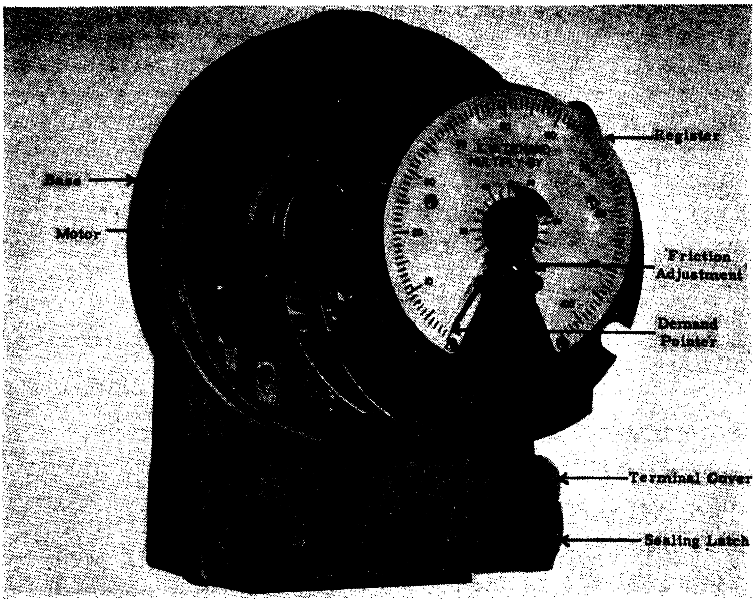


Fig. 15-39. Type AG-32A Demand Meter

Types AG-3A, AG-32A, and AG-4A demand meters are similar to the AG-3, AG-32, and AG-4 respectively, except that they are for use on alternating current.

In the direct-current types the timing device consists of a clock movement wound by means of a small d-c motor which is energized continuously. Substantially constant torque is delivered to the main gears by a brake control system which stalls the motor when the main spring is wound to a predetermined number of convolutions.

Direct-current type demand meters can also be obtained with an electromagnetic device which blocks the balance wheel when the motor current is interrupted. When operation is resumed, the balance wheel is released, and the motion of the balance wheel in returning to a center position is sufficient to start the escapement. This action assures starting of the escapement and keeps the main spring from running down.

In the alternating-current type demand meters, the timing device consists of a synchronous motor driving the interval selector cams through the necessary reduction gearing.

Standard demand intervals for all types are 15 and 30 minutes. A 100-division demand scale is provided. When furnished for 15-minute demand interval, 100 impulses are required for 100 divisions on the scale. AG-3, AG-32, AG-3A, and AG-32A 30-minute interval meters can be furnished so that either 100 or 200 impulses are necessary for the full-scale deflection of 100 divisions. The AG-4 and AG-4A require 200 impulses for a full-scale deflection of 100 divisions.

Contact Devices

All Sangamo Type H, HC, HF, J, L-2, L-3, and LC meters may be equipped with contact devices for operating external maximum demand meters.

THERMAL TYPE DEMAND METERS

Sangamo Lincoln thermal type maximum demand meters are supplied as *Watt Demand Meters* and as *Ampere Demand Meters*. Both are available in

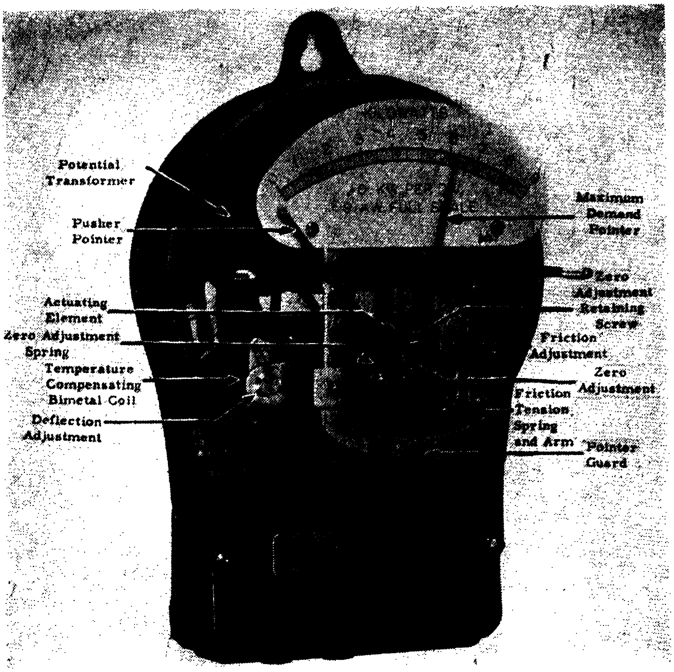


Fig. 15-40. Type WD Watt Demand Meter

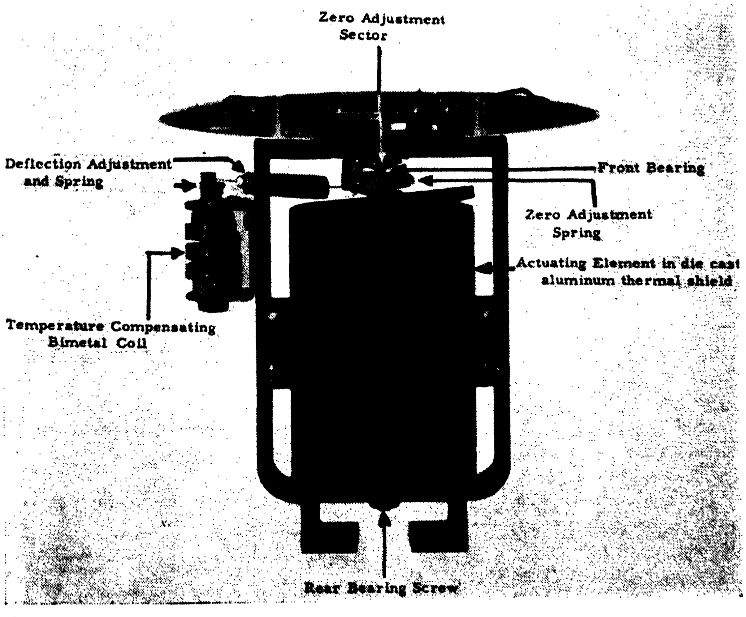

Zero Adjustment Sector
Deflection Adjustment and Spring
Front Bearing
Zero Adjustment Spring
Actuating Element in die cast aluminum thermal shield
Temperature Compensating Bimetal Coil
Rear Bearing Screw

Fig. 15-41. Lincoln Watt Demand Meter Actuating Element

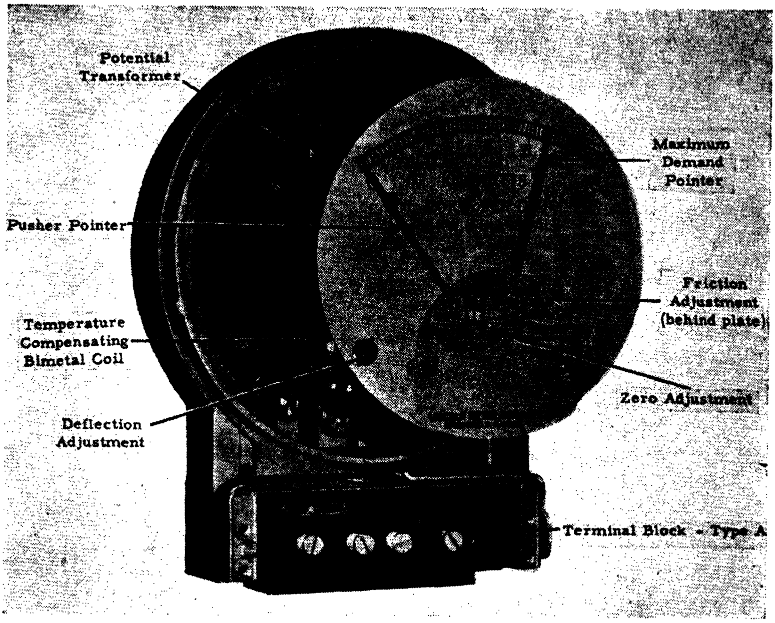


Fig. 15-42. Lincoln Type WDA Single-phase Watt Demand Meter

indicating and graphic forms in either the self-contained or instrument transformer types. The self-contained type is furnished in sizes from 5 to 100 amperes full scale, and is available with standard A or S meter base, and for switchboard mounting.

Type WD Watt Demand Meter

The WD demand meter was produced only in bottom-connected construction. The basic element and principle of operation is the same as described for the later types. In Type WD single-phase meters, shunts were employed to reduce the current to the actuating element. Fig. 15-40.

Types WDA, WDP, and WDS Watt Demand Meters

Types WDA, WDP, and WDS demand meters supersede the Type WD. They are used on alternating-current circuits to measure the demand in watts. The actuating element, Fig. 15-41, is 5-ampere nominal rating. All meter ratings contain current transformers, the various capacities being obtained by a change in the transformer ratio. These meters are temperature-compensated.

The single-phase Type WDA meter

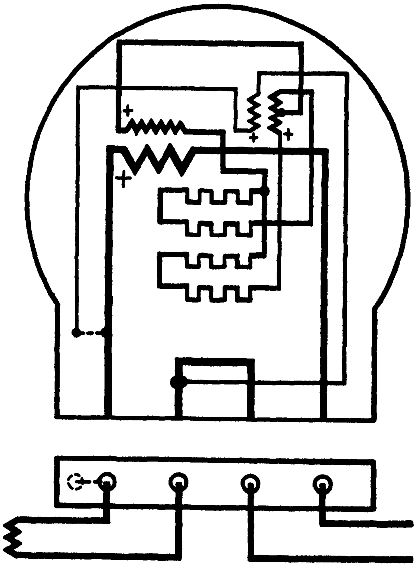


Fig. 15-43. Sangamo-Lincoln Single-phase Type WDA Watt Demand Meter, internal wiring diagram

is illustrated in Fig. 15-42. See Fig. 15-43 for connections. Fig. 15-44 illustrates the polyphase Type WDP meter.

Types JWA and JWS

Types JWA and JWS are single-phase combination watthour-thermal demand meters. The JWA meter has an A connection block, and the JWS meter is for socket mounting. In both types the watthour meter element is a Type JA. The watt-demand meter element is a standard Lincoln thermal demand meter except for the primary of the current coil, which is formed to connect to the terminals of the watt-hour meter. The two elements are entirely separate, except for being in one base and cover, and utilizing a single set of connections. Fig. 15-45.

Type AD Ampere Demand Meter

Type AD meters are for use on either alternating- or direct-current circuits. The basic element operation and construction are similar to the Type WD watt demand meter. Fig. 15-46.

The Type ADT three-wire meter is for use on alternating current only and employs a built-in three-wire current transformer supplying a two-wire meter circuit. The neutral is not carried through this meter.

The Type ADS, for alternating current only, two- or three-wire, is similar in principle to the ADT, but is arranged for socket mounting.

Types CCW and CCA Graphic Demand Meters

Graphic meters are supplied in the watt demand meter form designated as Type CCW, and in the ampere demand meter form designated as CCA. The complete graphic meter is illustrated in Fig. 15-47. It is similar to the indicating type with the addition of chart drive.

The circuits and operating principle of the graphic meters are identical with the indicating type, a pen replacing the indicating pointer. The chart is driven by either a synchronous motor, electrically-wound clock, or key-wound clock. The chart-driving

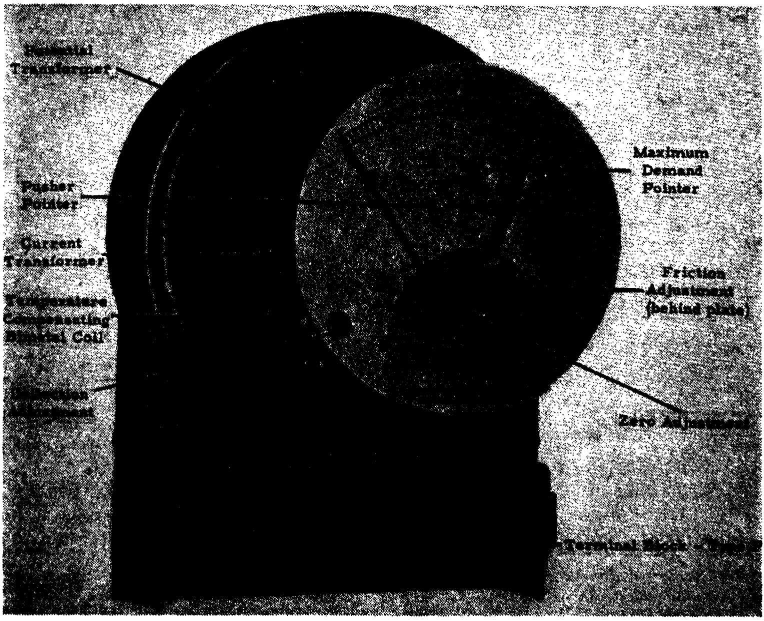


Fig. 15-44. Lincoln Type WDP Polyphase Watt Demand Meter

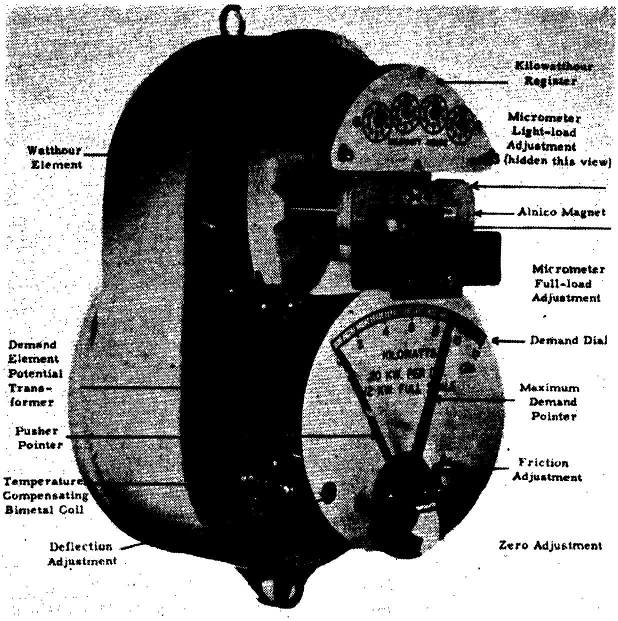


Fig. 15-45. Combination Single-phase Watthour and Demand Meter Type JWS

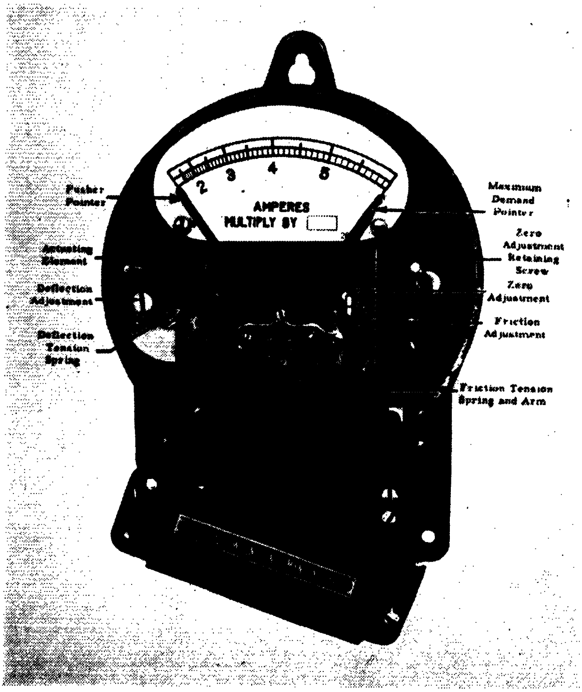


Fig. 15-46. Type AD—2-wire Ampere Demand Meter

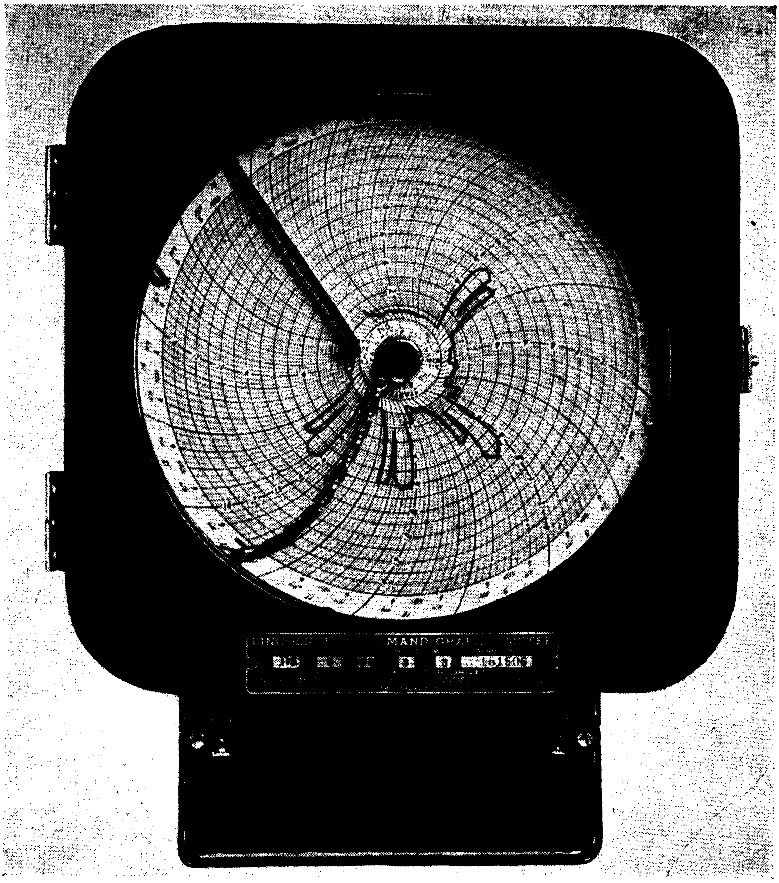
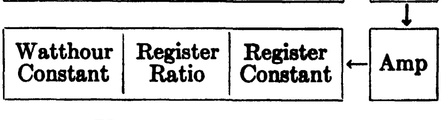


Fig. 15-47. Lincoln Type CCW Graphic Watt Demand Meter

mechanism is equipped with a triangular-shaped attachment which can be changed to obtain 2-, 8-, 16-, or 32-day operation of the chart.

DIRECTIONS FOR USE OF TABLES

The constants tables, Nos. 15-E and 15-F, are for a-c and d-c watthour meters. These tables are used by indexing from the proper type over to the correct voltage, then down to the ampere rating, and from there on the same horizontal line over to the corresponding constant data, as shown in the key below.



Key for Constants Tables

TABLE 15-A

METER DATA

SANGAMO DIRECT-CURRENT METERS

Description of Data		Type D (Late Model)	Type D-5
First manufactured	(year)	1908	1913
Meter disk speed	(rpm)		
5 ampere meters (with 500 watt load)		12½	
All larger capacities (with 1000 watts load or multiple)		25	25
Torque at full load (10 amp. meter)	(mmg)	55	60
Upward thrust of moving element	(grams)	3	3
Ratio of torque to thrust on jewel		18	20
Current coil drop at full load (10 amp. meter)	(volts)	0.03	0.03
Shunt drop in shunted type	(volts)	0.075	
Current circuit drop for internally shunted meters	(volts)		0.06
Current circuit drop with box type or open type shunts	(volts)		0.075
Current coil loss at full load (10 amp. meter)	(watts)	3.0	3.0
Current circuit loss for externally shunted meters	(watts)	7.5	7.5
Potential coil current (110 volts)	(amps)	.055	.041
Potential coil loss (110 volts)	(watts)	6.0	4.5
Potential coil resistance (cold)	(ohms)	1535	1800
Resistance in series with potential coil (110 volt meter)	(ohms)	450	900

TABLE 15-B

METER DATA

SANGAMO ALTERNATING-CURRENT METERS

Description of Data		Type B Guttman	Type H (First Model)	Type H (Late Model)		Type	Type	Type	Type	Type
				(60 cy)	(25 cy)	HC	HF	L2	L3	J
First manufactured	(year)	1901	1911	1914	1914	1928	1934	1937	1939	1939
Disk speed with 500 watts load per element	(rpm)	50	40	40	25	25	25	25	25	13$^{3}/_{8}$
Full load torque	(mmg)	16	40	48	32	47	47	72	75	56
Weight of moving element	(grams)	25	15.6	15	15	15	15	22.8	22.8	16
Ratio of torque to weight		0.64	2.5	3.2	2.1	3.1	3.1	3.15	3.3	3.5
Current coil drop at full load	(volts)	0.40	0.1	.12		.2	.2	.063		.06
Current coil loss at full load	(watts)	1.0	0.5	0.33		.26	.26	.13		.11
Potential coil loss at 60 cycles	(watts)	1.5	1.6	1.1		1.3	1.3	1.05	1.0	1.3
at 25 cycles	(watts)				1.6					
Potential coil current 60 cycles	(amps)		.037	.035		.037	.038	.06	.067	.091
Potential coil volt-amperes 60 cycles	(v-a)		4.07	3.85		4.25	4.37	7.2	8.0	10.0
Potential coil Power Factor	(%)	50	40	30		30	30	15	12.5	12
Starting load—per cent. of full load watts	(%)					½	¼	¼	¼	$^{3}/_{16}$
Range of adjustments										
Full load	(%)					90–125	90–120	80–130	80–130	88–112
5% load	(%)					70–125	75–120	75–125	75–125	52–129
Full load current—50% power factor	(%)						90–110	95–105	95–105	94–106
Above data based on meter rated	(amp)	5	5	5	5	5	5	5	5	5
	(volt)	110	110	110	110	115	115	120	120	120

TABLE 15-C

CONSTANTS FOR SANGAMO D-5

AMPERE HOUR METERS

Rating in Amperes	Amp. Hours per Rev. of Disk	Amp. Secs. per Rev. of Disk	Amp. Hrs. per Rev. of First Dial Pointer	Register Constant	Register Ratio	Gear Ratio
10	$^{1}/_{100}$	36	100	10	200	10000
20	$^{1}/_{50}$	72	100	10	100	5000
30	$^{3}/_{100}$	108	100	10	$66^{2}/_{3}$	$3333^{1}/_{3}$
40	$^{1}/_{25}$	144	100	10	50	2500
60	$^{3}/_{50}$	216	100	10	$33^{1}/_{3}$	$1666^{2}/_{3}$
80	$^{2}/_{25}$	288	100	10	25	1250
100	$^{1}/_{10}$	360	100	10	20	1000
150	$^{3}/_{20}$	540	100	10	$13^{1}/_{3}$	$666^{2}/_{3}$
200	$^{1}/_{5}$	720	100	10	10	500
300	$^{3}/_{10}$	1080	1000	100	$66^{2}/_{3}$	$3333^{1}/_{3}$

Higher current ratings proportional.

TABLE 15-D

CONSTANTS FOR SANGAMO NF and NT

AMPERE HOUR METERS

Rating in Amperes	Amp. Hrs. per Rev. of Disk	Amp. Secs. per Rev. of Disk	Rating in Amperes	Amp. Hrs. per Rev. of Disk	Amp. Secs. per Rev. of Disk
10	$^{1}/_{180}$	20	80	$^{2}/_{45}$	160
20	$^{1}/_{90}$	40	100	$^{1}/_{18}$	200
30	$^{1}/_{60}$	60	150	$^{1}/_{12}$	300
40	$^{1}/_{45}$	80	200	$^{1}/_{9}$	400
60	$^{1}/_{30}$	120	300	$^{1}/_{6}$	600

Higher current ratings proportional.

TABLE 15-E

CONSTANTS AND REGISTER RATIO DATA

FOR SANGAMO D-C AND A-C WATTHOUR METERS

Type				VOLTAGE																		
D, Direct-Current, 2-Wire				110		220		500		600												
D-5, Direct-Current	2-Wire				100–125		200–250		450–575		600–700											
	3-Wire						110–220															
H* **	(Single-Phase, 2-Wire, 40 to 133 Cycle)											115			230				440			
	(Single-Phase, 3-Wire, 40 to 133 Cycle)														230				440			
	(Three-Phase, 3-Wire, 40 to 133 Cycle)														115				230			
HC **	(Single-Phase, 2-Wire, 25 to 60 Cycle)												115			230						
	(Single-Phase, 3-Wire, 25 to 60 Cycle)															230						
	(Three-Phase, 3-Wire, 25 to 60 Cycle)															115				230		
HF **	(Single-Phase, 2-Wire, 25 to 60 Cycle)													115			230					
	(Single-Phase, 3-Wire, 25 to 60 Cycle)																230					
	(Three-Phase, 3-Wire, 25 to 60 Cycle)																115				230	
L-2	(Single-Phase, 3-Wire, 50 to 60 Cycle)																240					
	(Three-Phase, 3-Wire, 50 to 60 Cycle)																120				240	
L-3 (Three-Phase, 4-Wire, 50 to 60 Cycle)																		120				240
Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	Gear Ratio (R_g)	AMPERE RATING																		
5/24	960	1	48000									5										
1/3	600	1	30000										5									
1/3	300	1	30000											5								
5/12	480	1	24000									10			5							
5/8	320	1	16000									15										
2/3	300	1	15000	5																		
2/3	300	1	15000	10	10								10			5						
2/3	150	1	15000											10			5					
5/6	240	1	12000												10				5			
1	200	1	10000										15									
1	100	1	10000											15				5				
1 1/24	192	1	9600									25										
1 1/4	160	1	8000												15							
1 1/3	150	1	7500			5																
1 1/3	150	1	7500	20		10	10									10				5		
1 1/3	75	1	7500														10				5	
1 2/3	120	1	6000		25								25						10			
1 2/3	60	1	6000											25								
2	100	1	5000	30												15						
2	50	1	5000														15					5
2 1/12	96	1	4800									50			25							
2 1/2	80	1	4000																15			
2 2/3	75	1	3750	40		20														10		
2 2/3	37 1/2	1	3750																		10	
3	33 1/3	1	3333 1/3															15				
3 1/8	64	1	3200									75										
3 1/3	60	1	3000					5														
3 1/3	60	1	3000		50		25	10	10				50			25						
3 1/3	30	1	3000											50			25					
4	50	1	2500	60		30				5												
4	50	1	2500							10	10									15		
4	25	1	2500																		15	
4 1/6	48	1	2400									100			50				25			
5	40	1	2000		75								75									
5	20	1	2000											75								
5 1/3	37 1/2	1	1875	80		40																
6	16 2/3	1	1666 2/3																			15
6 1/4	32	1	1600									150			75							
6 2/3	30	1	1500		100		50	20					100			50				25		
6 2/3	15	1	1500											100			50				25	
8	25	1	1250			60				20												
8 1/3	24	1	1200						25													
8 1/3	240	10	12000									200			100				50			
10	20	1	1000		150		75	30			25											
10	10	1	1000															50				
16	200	10	10000										150			75						
10	100	10	10000											150			75					
10 2/3	18 3/4	1	937 1/2			80																
12	16 2/3	1	833 1/3							30												
12 1/2	160	10	8000									300			150				75			
13 1/3	15	1	750					40														
13 1/3	150	10	7500		200		100						200			100				50		
13 1/3	75	10	7500											200			100				50	
16	12 1/2	1	625							40												
16 2/3	120	10	6000						50			400			200				100			

TABLE 15-E (Continued)—SANGAMO Constants and Register Ratio Data

Type	VOLTAGE																		
D, Direct-Current, 2-Wire	110		220		500		600												
D-5, Direct-Current 2-Wire		100–125		200–250		450–575		600–700											
3-Wire				110–220															
H* ** (Single-Phase, 2-Wire, 40 to 133 Cycle)									115			230				440			
(Single-Phase, 3-Wire, 40 to 133 Cycle)												230				440			
(Three-Phase, 3-Wire, 40 to 133 Cycle)												115				230			
HC ** (Single-Phase, 2-Wire, 25 to 60 Cycle)										115			230						
(Single-Phase, 3-Wire, 25 to 60 Cycle)													230						
(Three-Phase, 3-Wire, 25 to 60 Cycle)													115				230		
HF ** (Single-Phase, 2-Wire, 25 to 60 Cycle)											115			230					
(Single-Phase, 3-Wire, 25 to 60 Cycle)														230					
(Three-Phase, 3-Wire, 25 to 60 Cycle)														115				230	
L-2 (Single-Phase, 3-Wire, 50 to 60 Cycle)														240					
(Three-Phase, 3-Wire, 50 to 60 Cycle)														120				240	
L-3 (Three-Phase, 4-Wire, 50 to 60 Cycle)															120				240

Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	Gear Ratio (R_g)	AMPERE RATING																		
20	10	1	500					60														
20	5	1	500																			50
20	100	10	5000		300		150				50		300			150				75		
20	50	10	5000											300			150				75	
20⅚	96	10	4800									500										
24	8⅓	1	416⅔							60									150			
25	80	10	4000						75						300							
26⅔	7½	1	375					80														
26⅔	75	10	3750		400		200						400			200				100		
26⅔	37½	10	3750											400			200				100	
30	66⅔	10	3333⅓								75											
32	6¼	1	312½							80												
33⅓	60	10	3000		500				100				500		400				200			
33⅓	30	10	3000											500								
40	50	10	2500		600		300				100					300				150		
40	25	10	2500														300	200			150	
41⅔	48	10	2400												500							
50	40	10	2000						150										300			
53⅓	37½	10	1875		800		400									400				200		
53⅓	18¾	10	1875														400				200	
60	33⅓	10	1666⅔								150											
66⅔	30	10	1500		1000		500		200							500			400			
66⅔	15	10	1500														500					
80	25	10	1250				600				200									300		
80	12½	10	1250																		300	
80	125	100	12500															400				200
83⅓	240	100	12000																500			
100	20	10	1000						300													
106⅔	18¾	10	937½				800															
106⅔	187½	100	9375																	400		
106⅔	93¾	100	9375																		400	
120	16⅔	10	833⅓								300											
120	83⅓	100	8333⅓															600				
133⅓	150	100	7500				1000		400											500		
133⅓	75	100	7500																		500	
160	125	100	6250								400											
160	62½	100	6250																			400
166⅔	120	100	6000						500													
200	100	100	5000						600		500											
240	83⅓	100	4166⅔								600											
240	41⅔	100	4166⅔																			600
266⅔	75	100	3750						800													
320	62½	100	3125								800											
333⅓	60	100	3000						1000													
400	50	100	2500								1000											

Higher current and voltage ratings proportional.

$K_t = K_h \times 3600$, in which K_t = Test Constant in watt seconds per disk revolution.

* Corresponding values of test constant and watthour constant for 25 and 30 cycle meters may be obtained by multiplying the 40 to 133 cycle values by 1.6.

** For 3-phase, 4-wire meters, multiply single phase constant by 3.

TABLE 15-F

CONSTANTS AND REGISTER RATIO DATA

FOR SANGAMO A-C WATTHOUR METERS

Type		VOLTAGE							
J Single-Phase, 2-Wire, 50 & 60 Cycle	120	240	480						
J Single-Phase, 3-Wire, 50 & 60 Cycle		240	480						
LC-2 Single-Phase, 3-Wire, 50 & 60 Cycle				240	480				
LC-2 Three-Phase, 3-Wire, 50 & 60 Cycle				120	240	480			
LC-3 Three-Phase, 4-Wire, 50 & 60 Cycle							120	240	480

Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	Gear Ratio (R_g)	AMPERE RATING								
.3		1	$33333\frac{1}{3}$	$2\frac{1}{2}$								
.6		1	$16666\frac{2}{3}$	5	$2\frac{1}{2}$		$2\frac{1}{2}$					
.9		1	$11111\frac{1}{9}$							$2\frac{1}{2}$		
1.2		1	$8333\frac{1}{3}$	10	5	$2\frac{1}{2}$	5	$2\frac{1}{2}$				
1.8		1	$5555\frac{5}{9}$	15						5	$2\frac{1}{2}$	
2.4		1	$4166\frac{2}{3}$		10	5	10	5	$2\frac{1}{2}$			
3.0		1	$3333\frac{1}{3}$	25								
3.6		1	$2777\frac{7}{9}$		15		15			10	5	$2\frac{1}{2}$
4.8		1	$2083\frac{1}{3}$			10		10	5			
5.4		1	$1851\frac{23}{27}$							15		
6.0		1	$1666\frac{2}{3}$	50	25		25					
7.2		1*	$1388\frac{8}{9}$			15		15			10	5
9.0		1*	$1111\frac{1}{9}$							25		
9.0		1	$1111\frac{1}{9}$	75								
9.6		1*	$1041\frac{2}{3}$						10			
10.8		1*	$925\frac{25}{27}$								15	
12.0		1*	$833\frac{1}{3}$		50	25	50	25				
12.0		1	$833\frac{1}{3}$	100								
14.4		1*	$694\frac{4}{9}$						15			10
18.0		1*	$555\frac{5}{9}$							50	25	
18.0		10	$5555\frac{5}{9}$	150	75		75					
21.6		1*	$462\frac{26}{27}$									15
24		1*	$416\frac{2}{3}$			50		50	25			
24		10	$4166\frac{2}{3}$	200	100		100					
27		10	$3703\frac{19}{27}$							75		
36		1*	$277\frac{7}{9}$								50	25
36		10	$2777\frac{7}{9}$	300	150	75	150	75		100		
48		1*	$208\frac{1}{3}$						50			
48		10	$2083\frac{1}{3}$	400	200	100	200	100				
54		10	$1851\frac{23}{27}$							150	75	
60		10	$1666\frac{2}{3}$	500								
72		1*	$138\frac{8}{9}$									50
72		10	$1388\frac{8}{9}$		300	150	300	150	75	200	100	
96		10	$1041\frac{2}{3}$		400	200	400	200	100			
108		10	$925\frac{25}{27}$							300	150	75
120		10	$833\frac{1}{3}$		500		500					
144		100	$6944\frac{4}{9}$			300		300	150	400	200	100
180		100	$5555\frac{5}{9}$							500		
192		100	$5208\frac{1}{3}$			400		400	200			
216		100	$4629\frac{17}{27}$								300	150
240		100	$4166\frac{2}{3}$			500		500				
288		100	$3472\frac{2}{9}$						300		400	200
360		100	$2777\frac{7}{9}$								500	
384		100	$2604\frac{1}{6}$						400			
432		100	$2314\frac{22}{27}$									300
480		100	$2083\frac{1}{3}$						500			
576		100	$1736\frac{1}{9}$									400
720		100	$1388\frac{8}{9}$									500

Higher current and voltage ratings proportional.
* Meters equipped with direct-reading 5 circle registers. Values given for LC-3 meters also apply to LC-$2\frac{1}{2}$ meters.

SECTION 16

WESTINGHOUSE ELECTRIC CORPORATION METERS

The following descriptive material pertains to types of meters placed in production since 1924 by the Westinghouse Electric Corporation. Information on other direct- and alternating-current types may be found in the Appendix and in previous editions of the *Electrical Metermen's Handbook.* Detailed data and constants, however, are included for all types.

Only salient features and major changes in meters are described. More detailed information concerning the meter types may be obtained from the manufacturer's published material.

ALTERNATING-CURRENT WATT-HOUR METERS

Single-Phase Meters

Type OB One-Element

This meter represented a major change from the preceding Type OA. The full- and light-load adjustments were changed, the electromagnet was designed with both coils on the same side of the disk, and the frame and base were made of drawn steel. The adjustments for Type OB meters are similar to those shown for the Type CA in Fig. 16-1.

The following changes and modifications have been made. The first change provided a modified terminal base, a lengthened disk shaft, a modified light load adjustment and a new top bearing for meters numbered above 9,000,000. Permanent magnet temperature compensation was added to meters between serial nos. 9,500,000 and 10,375,000. Complete temperature compensation was provided on meters above serial no. 10,375,000. The overload accuracy of meters above serial no. 10,655,000 was extended by means of a magnetic shunt added between the series poles. Edge of disk knurled to facilitate stroboscopic testing was provided on meters above serial no. 11,100,000.

Type OB Detachable

This meter differed from preceding types in the method of making line and load connections, which was by means of pins on the back of the meter that engage in spring sleeves in the meter socket. Only one seal is required to protect the meter and its connections to line and load wires.

Type OB—25 Cycle

The 25-cycle Type OB meter employed an electromagnet and construction similar to the Type OA.

Type OC—One-Element

The Type OC meter superseded the Type OB. The cover was secured to the base by bayonet joints, eliminating the use of cover studs. The meter had greater thermal capacity and was compensated for temperature and overload errors. Standard ratings of 5, 15 and 50 amperes were adopted.

The electromagnet was of the same general shape as that of the Type OA meter, having potential and series poles on opposite sides of the disk. Temperature compensation was of the same principle as that used in the Type OB, but the permanent magnet compensation consisted of a clip which bridged the air gap beneath the disk.

Full-load adjustment was obtained by turning the laminated iron keeper above the magnet until it shunted the required amount of flux from the permanent magnet.

Light-load adjustment was controlled by a micrometer screw.

Power factor adjustment was made by varying the resistance of a loop on the series poles. All adjustments are similar to the Type CA meter. Fig. 16-1.

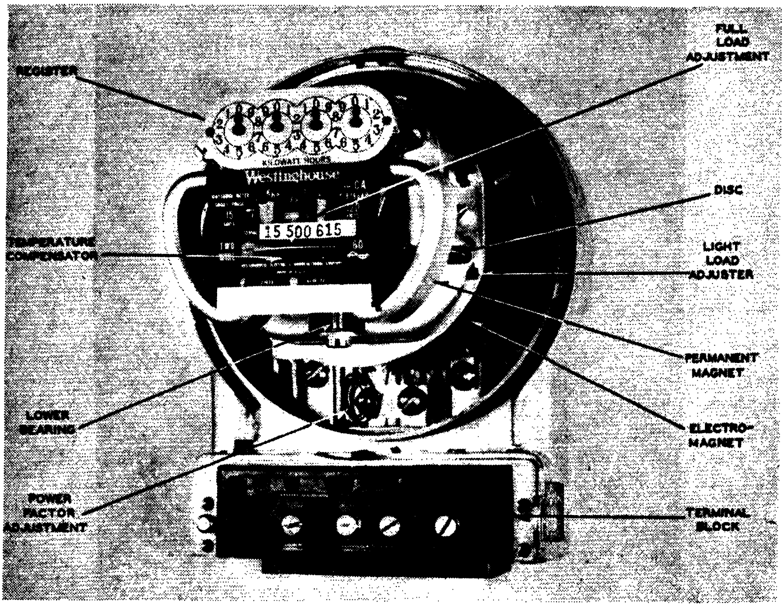


Fig. 16-1. Type CA Single-phase Watthour Meter

Type OC—One-Element—Detachable

This meter is identical to the Type OC except for mounting details, which were the same as those of the OB detachable meter.

Type CA—One-Element

This meter incorporates the OC mechanism within the Type A base. The meter has a deeper glass cover, a shallow, die-cast aluminum base, and an improved sealing arrangement. One size of base is used for all ratings. For adjustments see Fig. 16-1.

Type CS—One-Element

This meter is similar to the Type OC except that it is of the detachable or socket type for mounting in the Type S socket. Switch blade terminals on the rear of the meter engage in connecting clips in the socket. Fig. 16-2.

Type CB—One-Element

This meter is for switchboard service. Stud terminals are provided for rear connections. Cases can be supplied for either semi-flush or projection mounting. The meter mechanism is similar to the Type CA or CS.

Type CB-F—One-Element

This meter is similar to the Type CB except that the meter mechanism is mounted on a chassis which is removable from the case without disturbing the connections. Knife-blade test switches and circuit-closing connections are built into the case.

Polyphase Meters

Polyphase meters and their application according to their use on the various circuits are shown on page 433.

The letters A, B and S in the meter type indicate the following:

A—Column 2 of table (e.g., CA-2) indicates that the meter is bottom-connected, mounted in an A type die-cast aluminum base.

B—Column 4 of table (e.g., CB-2) indicates that the meter is for switchboard mounting. See Figs. 16-3 and 16-4.

S—Column 1 of table (e.g., CS-2) indicates that the meter is of the detachable or socket type.

POLYPHASE METER APPLICATION TABLE

APPLICATION	No. of Elements	1	2	3	4
		S Type Meter	A Type Meter	Large Type Meter	*B Switchboard Type Meter
SELF-CONTAINED TYPE					
Three-phase, 3-wire Two-phase, 4-wire	2	CS-2	CA-2	C-2	CB-2
Single-phase, 3-wire Two-phase, 3-wire Network, 3-wire (From neutral and 2 phases of a 3-phase, 4-wire, Y circuit.)	2	CS-5	CA-5	C-5	CB-2
Two-phase, 5-wire	2	CS-10	CA-10	C-10	CB-10
Three-phase, 4-wire, wye	2½ 3	CS-8 CS-3	CA-8 CA-3	C-8 C-3	CB-8 CB-3
Three-phase, 4-wire delta	2 3	CS-7 CS-9	CA-7 CA-9	C-7 C-9	CB-7 CB-9
Totalizing SP 2-wire and three-phase, 3-wire	3	CS-4	CA-4	C-4	CB-4
Totalizing SP 3-wire and three-phase, 3-wire	3	CS-6	CA-6	C-6	CB-6
Totalizing—Two three-phase, 3-wire circuits or two two-phase, 3-wire circuits	4	—	—	—	CB-32
Totalizing—Two three-phase, 4-wire wye circuits	4 Split Coil	—	—	—	CB-38
TRANSFORMER TYPE For Use with Both Current and Potential Transformers or with Current Transformers Only					
Single-phase, 3-wire Two-phase, 3-wire Three-phase, 3-wire Two-phase, 4-wire Network, 3-wire (From neutral and 2 phases of a 3-phase, 4-wire, Y circuit.)	2	CS-2	CA-2	C-2	CB-2 CB-2F
Two-phase, 5-wire	2	CS-10	CA-10	C-10	CB-10 CB-10F
	2	CS-2	CA-2	C-2	CB-2 CB-2F
Three-phase, 4-wire, wye	2	CS-2	CA-2	C-2	CB-2 CB-2F
	2½	CS-8	CA-8	C-8	CB-8 CB-8F
	3	CS-3	CA-3	C-3	CB-3 CB-3F
Three-phase, 4-wire delta	2	CS-2	CA-2	C-2	CB-2 CB-2F
	2	CS-7	CA-7	C-7	CB-7 CB-7F
	3	CS-9	CA-9	C-9	CB-9 CB-9F
Totalizing—SP 2-wire and three-phase, 3-wire	3	CS-4	CA-4	C-4	CB-4 CB-4F
Totalizing—SP 3-wire and three-phase, 3-wire	3	CS-6	CA-6	C-6	CB-6 CB-6F
Totalizing—Two three-phase, 3-wire circuits or two two-phase, 3-wire circuits	4	—	—	—	CB-32F
Totalizing—Two three-phase, 4-wire wye circuits	4 Split Coil	—	—	—	CB-38F

* Type S Meters as listed in the first column are also used as Switchboard Meters.

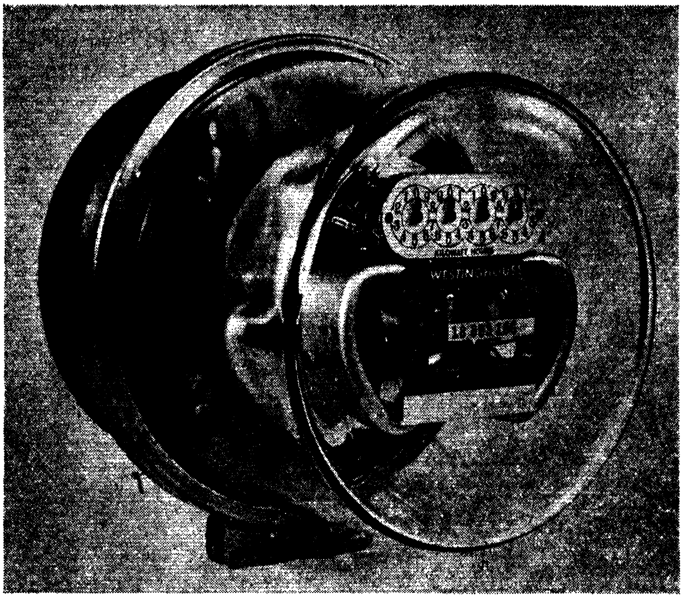


Fig. 16-2. Type CS Single-phase Watthour Meter

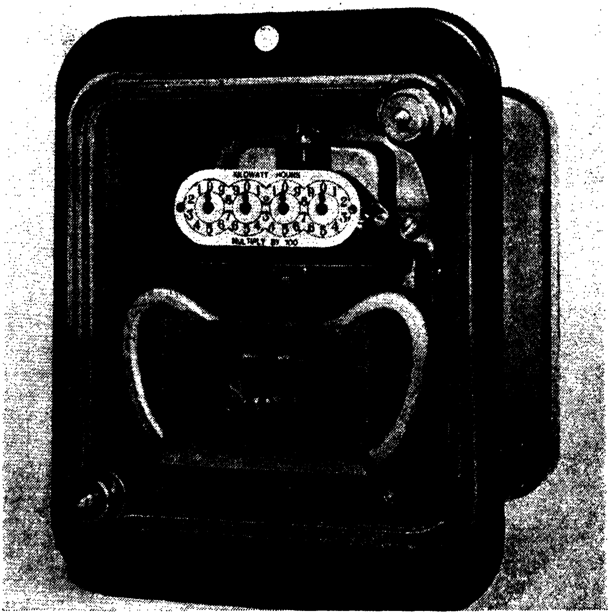


Fig. 16-3. Polyphase Switchboard Watthour Meter, Type CB-2, back connected

Meters of the A, B and S types, Columns 1, 2 and 4 of the table, are equipped with electromagnets having current and potential poles on the same side of the disk. One disk per element is used. The balance adjustment consists of a movable iron plate in the electromagnet air gap. Meters

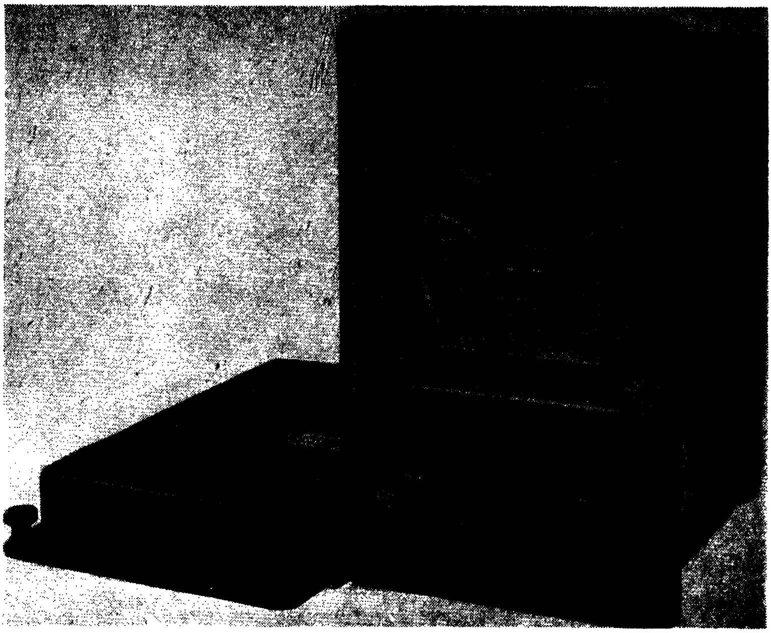


Fig. 16-4. Polyphase Switchboard Watthour Meter, Type CB-2F, front connected

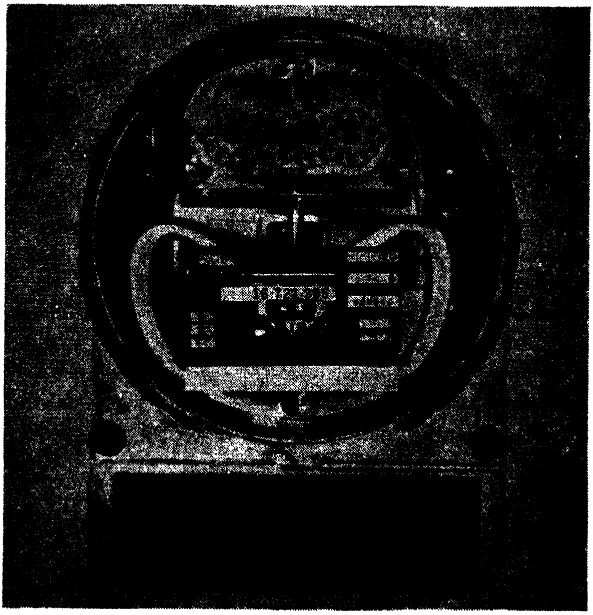


Fig. 16-5. Type CA-2 Polyphase Watthour Meter

of serial numbers above 15,000,000 have accuracies and thermal capacities comparable to the large electromagnet supplied in the CA, CB and CS single-phase meters. Fig. 16-5.

Meter types in Column 3 of the table are similar to the Type OC single-phase meter except for the addition of phase balancing adjustments and a mechanical power factor adjustment.

Potential indicating lamps are sup-

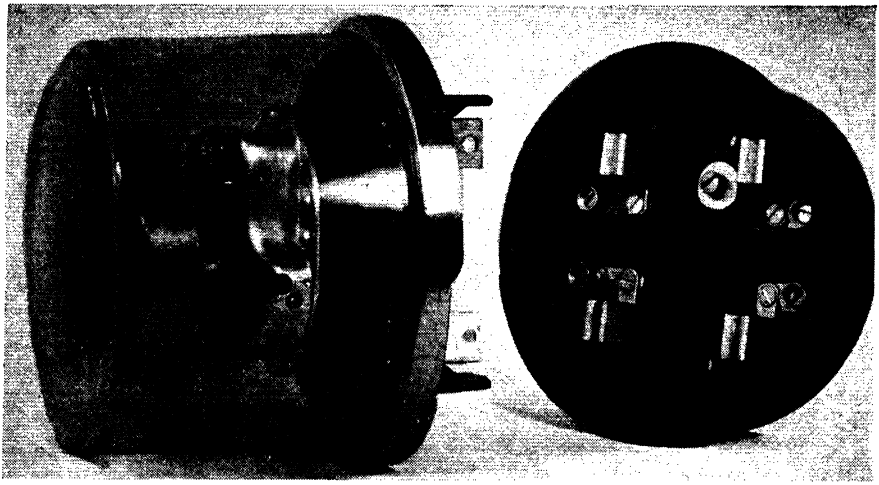


Fig. 16-6. Type CS Single-phase Meter and Socket

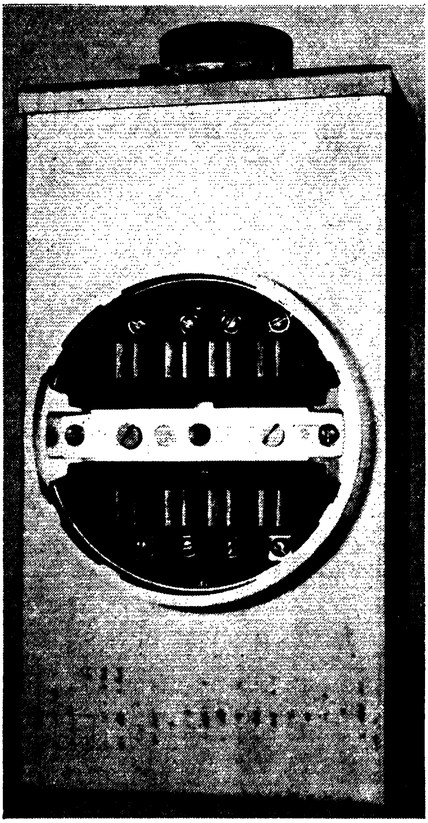


Fig. 16-7. Type S Polyphase Socket

plied on self-contained polyphase meters when so ordered and on all transformer type polyphase meters.

Type S Sockets

For single-phase meters, the same size socket and terminals are used in all capacities. Fig. 16-6. Disconnect screws enable the service to be disconnected without permanent removal of the meter. Auxiliary terminals that permit the removal of the meter without opening the circuit may be supplied for self-contained meters. All sockets for use with current transformer meters should be provided with circuit closing facilities. Polyphase sockets having the necessary additional terminals are available. Fig. 16-7.

Detachable meters may be tested by inserting a test jack between the socket and the meter. The customer's load is by-passed. A test jack for single-phase meters is shown in Figs. 16-8 and 16-9.

Varhour Meters

Types XCS and XCA Varhour Meters

Types XCS and XCA meters are similar to single-phase CS and CA meters with the addition of a resistor-condenser phase-shifting network in the potential circuit to cause them to

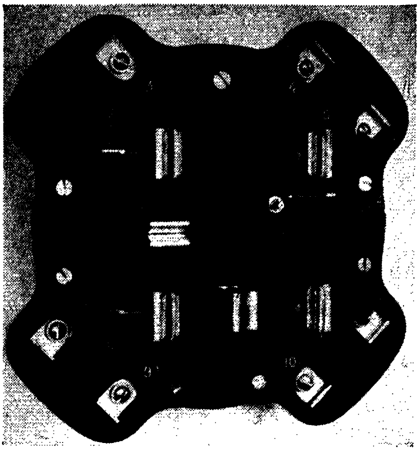


Fig. 16-8. Test Jack for Single-phase Meters, front view

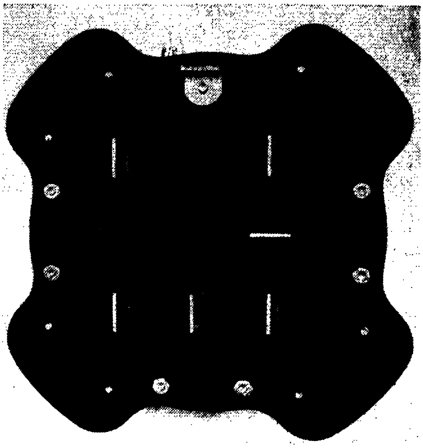


Fig. 16-9. Test Jack for Single-phase Meters, rear view

measure varhours. With these meters the use of an external phase shifter is eliminated. They are interchangeable in connections with standard watthour meters of similar types.

PORTABLE STANDARD WATTHOUR METERS

Type OB

These standards use electromagnets similar to those used in the Type OB single-phase meters, with serial numbers above 10,625,000. Full-load adjustment is accomplished by moving the iron keeper on the permanent magnet assembly. Light load is adjusted by moving a thin plate along the iron below the disk. The compensating winding on the series poles permits power factor adjustments by varying the length of the resistance wire closing the compensating winding. Fig. 16-10.

These standards are made in two- and five-current capacity sizes, 1 and 5 amperes, 1 and 10 amperes, and 1, 5, 10, 25 and 50 amperes. The five current capacities are available through the use of a drum switch. Two voltage ranges are available in each capacity size by means of a switch, either 120 and 240 volts, or 240 and 480 volts. See Table 16-R. A zero reset device is provided.

Test constants are given in Table 16-S.

Type CP

The Type CP, Fig. 16-11, utilizes an electromagnet similar in design to the OC but considerably larger. The permanent magnet was of the OA type which may be adjusted by moving it forward or backward as indicated by the arrows. A micrometer screw was used for final adjustment of full load. Later meters used the magnet shown in Fig. 16-12 adjusted similarly except that the clamping screw is at the bottom, and a keeper is used for the final adjustment. The light-load adjustment is shown on the right. Turning this screw moves a thin plate along the iron below the disk. The power factor is adjusted by varying the length of the resistance wire closing the compensating winding on the series poles. Some early meters had, in addition, a mechanical adjustment.

A brake is provided which prevents current creep at no potential. A zero reset device to return both pointers to zero is also provided.

The capacities manufactured are listed in Table 16-R. The two- and three-current capacity standards use separate current terminal posts and a small switch for changing potential connections. The five-current capacity standards use the drum switch.

Test constants are given in Table 16-S.

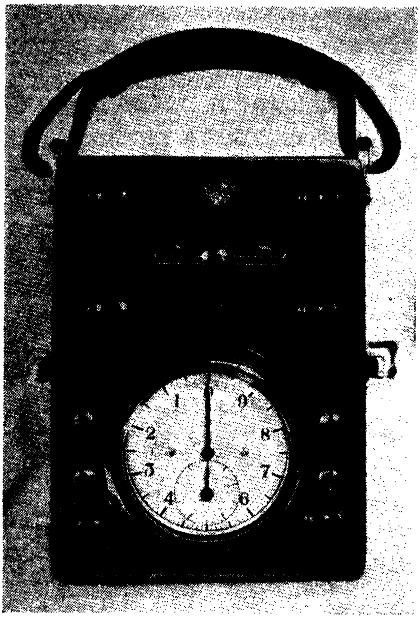


Fig. 16-10. Type OB Portable Standard Watthour Meter

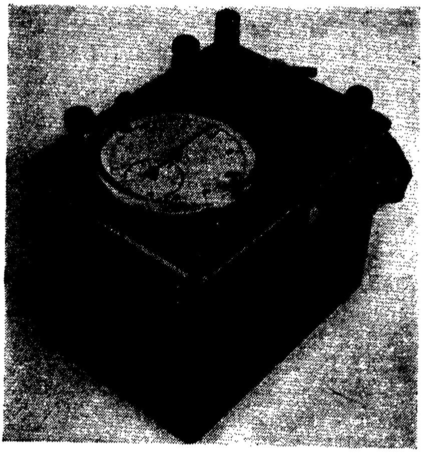


Fig. 16-11. Type CP Portable Standard Watthour Meter

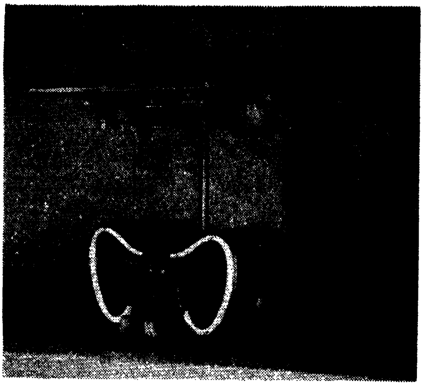


Fig. 16-12. Type CP Portable Standard Watthour Meter, internal view

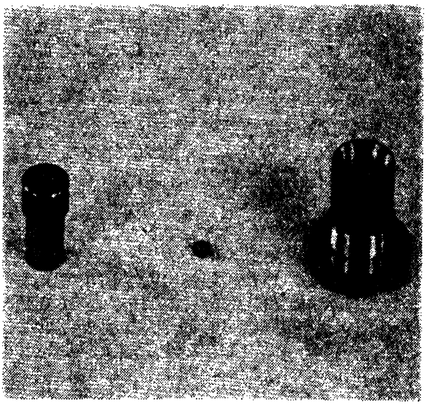


Fig. 16-13. Upper Jewel Bearing, Steel Ball and Lower Jewel Bearing

BEARINGS

All Westinghouse meters use the same type of lower bearing. It consists of a highly polished and hardened steel ball revolving between two cup-shaped sapphire jewels. No lubrication is required either for protection of parts or for reduction of friction. Fig. 16-13.

The top or guide bearing consists of a polished steel pin which fits into a ring bearing in the top of the disk shaft. Sealed in the disk shaft is a lubricant which continuously oils the pin. This lubricant under normal conditions does not have to be replaced.

INDICATING DEMAND REGISTERS

Each of these devices is fundamentally a complete demand meter embodying a watthour register for use on Westinghouse a-c watthour meters. With the exception of the Type RL, they are of the block interval type, integrating and averaging the demand over a definite demand interval. Kilowatthour consumption is recorded by means of conventional dials and pointers. In registers of the sweep-hand construction, the maximum kw demand is indicated by a friction pointer and a scale. In registers of the cumulative-dial construction, the maximum demand for each reset period is added to the cumulative reading by means of a set of dials and pointers.

Meters that are supplied with the Types RW or RW-2 demand registers are designated by the addition of the suffix W to the type number, for example, CA-2W. Similarly an L is added to the type number of meters supplied with RL or RL-2 demand registers, for example, CA-2L.

Type OB Register

Operating Principle—A gear meshes with the pinion on the watthour-meter shaft and through a worm, drives the kilowatthour and demand gear trains, actuating the demand pusher pointer until the demand interval has elapsed.

At the end of each demand interval, as measured by a synchronous motor, an engaging sector is driven rapidly by a worm, and demeshes the gearing momentarily, while the pusher pointer is reset by gravity. The synchronous motor serves not only as a timing device, but also drives the sector during the resetting period.

Rating and Dial Marking—A name plate on the top of the demand register gives the serial number, nominal rating in kw, the voltage, frequency, and demand interval for which it is designed. Register scales provide for 25% overload when based on a nominal rating of 100 volts or multiples thereof.

The Type OB register is designed for use with Type OB meters, both single-phase and polyphase.

The scale capacity is independent of the demand interval. The demand interval affects only the gear ratio design of the demand train. Thus a fifteen-minute demand register will reach its final block interval reading in half the time of a thirty-minute register when operating on the same load.

Type DR Register

This register was designed to provide a greater degree of accuracy and reliability than the preceding types.

Operating Principle—A gear meshes with the pinion on the watthour-meter shaft and, through a worm, drives the kilowatthour and demand gear trains, actuating the maximum demand pusher pointer until the demand interval has elapsed.

At the end of each demand interval as measured by a synchronous motor, the spring-operated reset mechanism is released and drives the pusher pointer back to its zero position.

The synchronous motor not only serves as the timing device but constantly winds the reset spring throughout the entire demand interval.

The maximum demand pointer is friction-coupled to its shaft in such a way as to retain its maximum position until it is restored to zero through the manual action of the reset mechanism.

Rating and Dial Marking—A name plate on the top of the demand register gives the serial number, the rating in kw, the voltage, frequency, and the demand interval for which it is designed. Demand registers for single-phase, self-contained meters have scales providing for 333 1/3% capacity when based on a rating of 120 volts or multiples thereof.

Registers for transformer type, single-phase and polyphase meters have a full scale value of 166 2/3% of full load at 120 volts rating.

The Type DR register is designed for use with Types OB, OC, CA, and CS single-phase meters, with the corresponding polyphase meters, and with the Type OA meter by means of an adaptor. A special cover with reset mechanism is required with demand registers.

The scale capacity is independent of the demand interval. The demand interval affects only the gear ratio design of the demand train. Thus a fifteen-minute demand register will reach its final block interval reading in half the time of a thirty-minute register when operating on the same load.

Type RW Register

The Type RW register operates on the integrated demand or block interval principle. See Fig. 16-14.

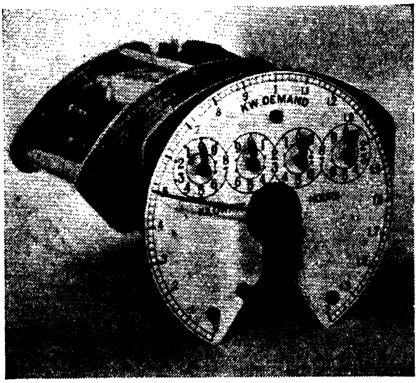


Fig. 16-14. Type RW Demand Register

Operating Principle — A sweephand pointer is advanced by a pusher to a point on the dial representing the kw demand as shown in Fig. 16-15. This pusher is operated by a gear train from the meter disk shaft. At the end of each demand interval, the timing mechanism opens a clutch which disengages the pusher from the driving gears. The pusher is then returned to zero by a resetting spring.

The sweephand pointer is held at the point of maximum demand by a friction brake. Resetting of this pointer is accomplished by manually operating a lever projecting through the glass cover.

The timing mechanism consists of a synchronous motor of the hysteresis type which actuates the interval gearing. The motor rotates at 600 rpm on 60 cycles. A 1-rpm output shaft is driven by the motor through an oil-immersed gear train. A clutch in the interval unit permits manual advancement of the interval gearing for testing purposes. The time remaining in any interval may be read by observing a marked gear at the top of the register.

The kilowatthour register is geared directly to the meter disk shaft at all times.

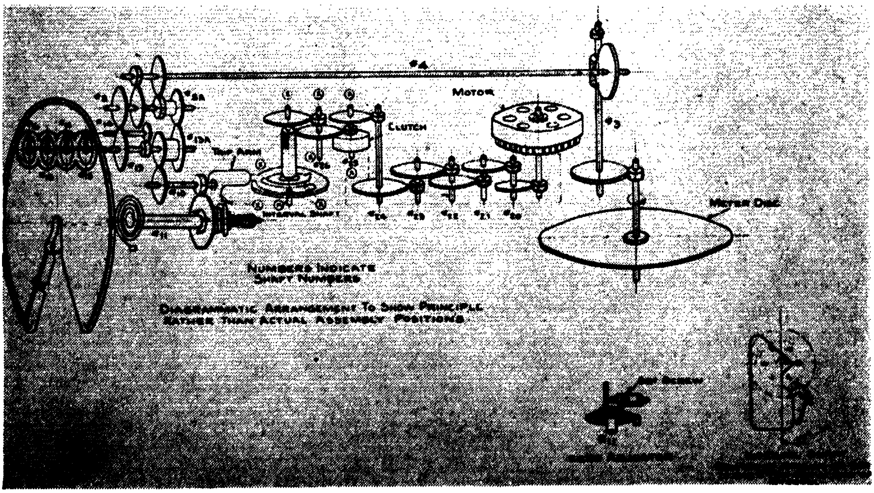

#4
#8A
MOTOR
CLUTCH
#3
#13A
TEST ARM
INTERVAL SHAFT
#24
#23
#22
#21
#20
#11
METER DISC
NUMBERS INDICATE SHAFT NUMBERS
DIAGRAMMATIC ARRANGEMENT TO SHOW PRINCIPLE RATHER THAN ACTUAL ASSEMBLY POSITIONS

Fig. 16-15. Schematic Diagram of Type RW Demand Register

Ratio and Dial Marking—The overload capacity and application of the registers are the same as for the Type DR.

Type RW-2 Register

The Type RW-2 register consists of the Type RW register modified so as to provide a cumulated value of previous maximum demands as well as the maximum demand during any reading period. The maximum demand for each reading period is added to the previous demands at the time of manual reset. Fig. 16-16.

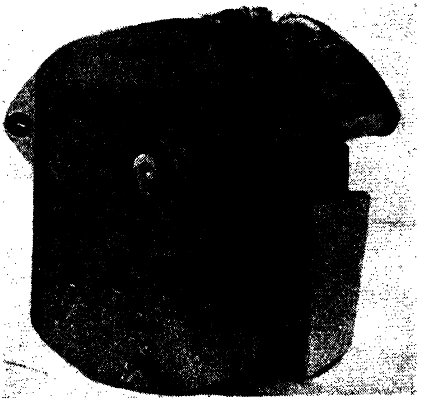


Fig. 16-16. Type RW-2 Demand Register

Operating Principle—This type differs from the Type RW in that the demand mechanism advances a train of gears a definite number of revolutions. When these gears are returned to their starting point, at the time of manual reset, they actuate a separate train of dials registering the demand. Fig. 16-17.

Manual reset is initiated by depressing and releasing the reset arm located in the front of the meter. This causes the synchronous motor to drive an additional train of gears which transfers the maximum demand reading to the cumulative dials.

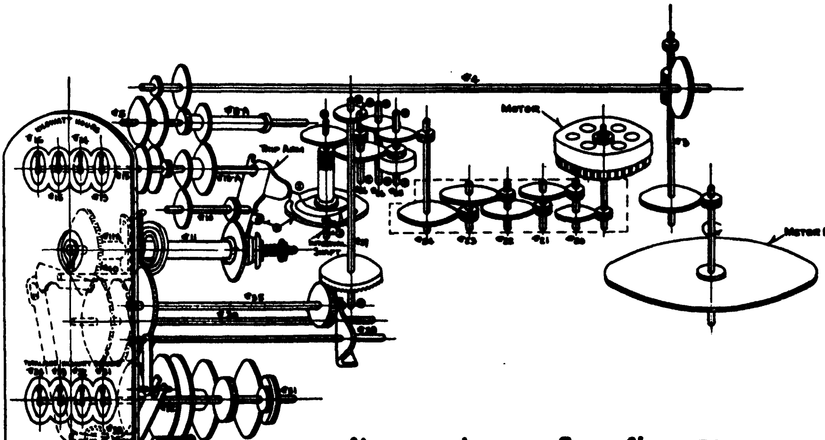
A test dial, located between the kilowatthour and the kilowatt dials, gives the approximate maximum demand since the last manual reset.

The application and overload capacity of these registers are the same as for the Type DR.

Type RL Register

This demand register operates on the lagged demand principle and is of the exponential or logarithmic type. It registers by direct mechanical drive throughout, and its accuracy therefore is that of the watthour meter and the timing motor. Fig. 16-18.

Principle of Operation—A representation of the principal parts of the



Numbers Indicate Shaft Numbers

Diagrammatic Arrangement To Show Principle Rather Than Actual Assembly Positions

Fig. 16-17. Schematic Diagram of RW-2 Demand Register

Fig. 16-18. Type RL-2 Demand Register

mechanism is shown in Fig. 16-19. The two principal features are the differential, and the ball with its driving disk *E*.

One side of the differential is driven by the watthour meter and the other by the timing motor, but in the opposite direction, each through a suitable train of gears. Any difference in speeds of these two drives will result in a rotational movement of the involute cam *C*, the greater the difference in the speeds the greater the movement. This movement of the cam is transmitted to the demand pointer through another set of gears.

The ball and its driving disk act as a variable speed transmission in the train between the timing motor and the differential. The surface speed of the ball is proportional to the distance of the ball contact point from the center of the disk *E*. With the ball at dead center of the disk, its surface speed will be zero; at the outer periphery of the disk, its speed will be a maximum. Since the ball is resting on the drum *F*, both will have the

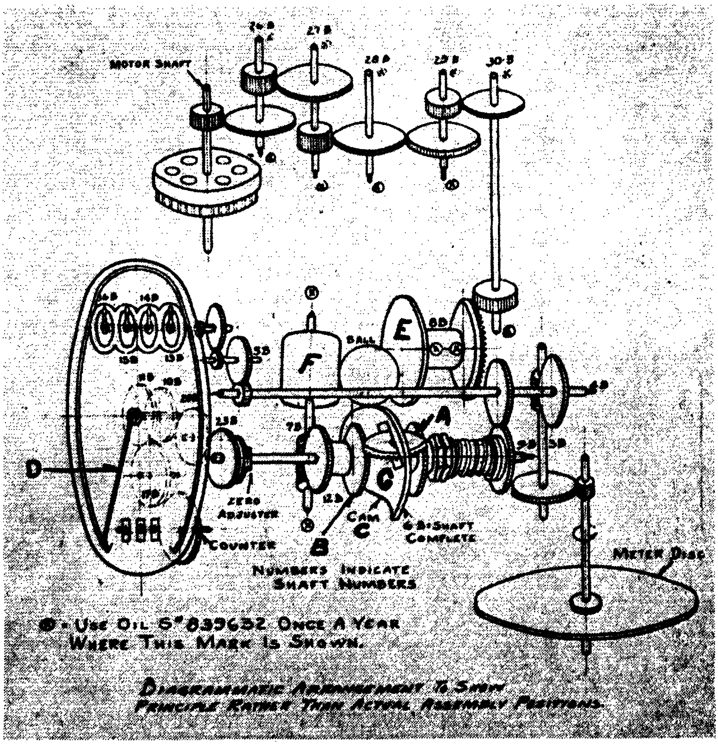

MOTOR SHAFT
26 B
27 B
28 B
29 B
30 B
14 B
14 B
15 B
13 B
5 B
F
BALL
E
8 D
4 B
A
23 B
7 B
D
ZERO ADJUSTER
12 B
CAM C
6 B: SHAFT COMPLETE
COUNTER
B
2 B
3 B
METER DISC
NUMBERS INDICATE SHAFT NUMBERS
⊗ = USE OIL S#839632 ONCE A YEAR WHERE THIS MARK IS SHOWN.
DIAGRAMMATIC ARRANGEMENT TO SHOW PRINCIPLE RATHER THAN ACTUAL ASSEMBLY POSITIONS.

Fig. 16-19. Schematic Diagram of Type RL-2 Demand Register

same surface speed, which the drum, in turn, imparts to the differential. The contact position of the ball against the driving disk depends upon the position of the involute cam *C* against which the ball also rests.

With no load upon the watthour meter, the ball is at dead center of the driving disk and, therefore, no motion is imparted to the differential either by the timing motor or the watthour meter. With no movement of the differential and its cam, there will be no movement of the demand pointer. As load is applied, one side of the differential is driven at a speed proportional to the load, causing the involute cam to move. The change in the position of the cam changes the location of the ball with respect to its driving disk, moving it toward the outer edge of the disk. The increasing speed of the ball's rotation is imparted to the other side of the differential resulting in a smaller difference in the two speeds. This action continues until the two speeds are equalized at which time the involute cam and the demand pointer remain stationary.

Since the rate at which the cam with its demand pointer moves is equal to the difference in the two speeds transmitted to the differential, it is evident that this rate starts off at a relatively high value, then becomes less and less as the difference in speeds approaches zero.

For the same change in load, the descending rate as the demand pointer returns to zero is exactly the same as the ascending rate. The demand interval is considered to be the time required for the register to indicate ninety per cent of the full value of a constant load suddenly applied.

Scale and Dial Marking—The kilowatt rating in demand is the same as that of the watthour meter and its usual integrating train.

A full scale value of 166 2/3% of the nominal kw rating of the watthour meter is provided.

The register is designed for use with Types CA and CS single-phase, and corresponding polyphase meters.

Type RL-2 Register

The Type RL-2 register is similar to the Type RL except for the addition of a totalized demand dial. This mechanism is actuated by resetting the maximum demand pointer, thus giving a cumulative record of the total maximum demands.

RECORDING WATTHOUR DEMAND METERS

These meters combine in one device a watthour meter and a recording demand meter. The demand mechanism is of the *block-interval* type, recording on a strip chart the demand integrated over a definite demand interval. A record is made on the chart for each interval.

The record is made on the chart by a pen which is mechanically operated from the watthour meter. At the end of each demand interval, as measured by a synchronous motor, the chart advances and the pen resets to zero. Table 16-U lists the constant data for the Type RA watthour demand meter.

Type RB

This type superseded the Type RA and employed improved electromagnets similar to Type OC. See Fig. 16-20.

The demand mechanism is designed to advance the pen to 80% of full scale based on a rating of 120 volts or multiples thereof. Full-scale deflection represents 125% of the kw rating of the meter.

Type R-2

This type supersedes the Type RB and employs elements of improved accuracy and thermal capacity. Improvements also have been made in the clock and paper-chart mechanism. Fig. 16-21.

Full scale ratings and chart markings correspond with those of the Type RB. Intervals of 15, 30 or 60 minutes are provided and the paper advances one-sixteenth of an inch every fifteen-minute period. Constant data are given in Table 16-W.

Meters in the R-2 line and their applications are:

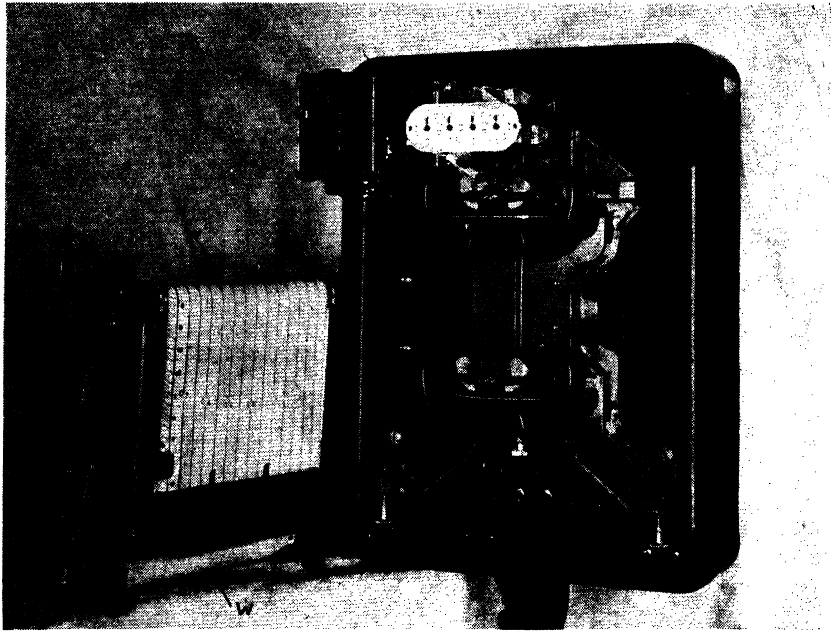


Fig. 16-20. Type RB Watthour Recording Demand Meter with Chart Carriage Removed

Type	*Number of Elements*	*Circuit Application*
R-2	2	3-phase, 3-wire 2-phase, 4-wire
R-3	3	3-phase, 4-wire
R-4	3	Totalizing 1-phase, 2-wire and 3-phase, 3-wire
R-6	3	Totalizing 1-phase, 3-wire and 3-phase, 3-wire
R-7	2	3-phase, 4-wire, delta
R-8	2½ Split Coil	3-phase, 4-wire, wye
R-9	3	3-phase, 4-wire, delta
R-10	2	2-phase, 5-wire
R-22	2 Duplex	3-phase, 3-wire 2-phase, 4-wire
R-23	3 Duplex	3-phase, 4-wire
R-27	2 Duplex	3-phase, 4-wire, delta
R-28	2½ Duplex	3-phase, 4-wire, wye
R-29	3 Duplex	3-phase, 4-wire, delta
R-32	4	Totalizing 3-phase, 3-wire or 2-phase, 4-wire

Type	*Number of Elements*	*Circuit Application*
R-42	2 Duplex-Differential	Totalizing 3-phase, 3-wire or 2-phase, 4-wire
R-43	3 Duplex-Differential	Totalizing 3-phase, 4-wire
R-52	4 Duplex	Totalizing 3-phase, 3-wire or 2-phase, 4-wire

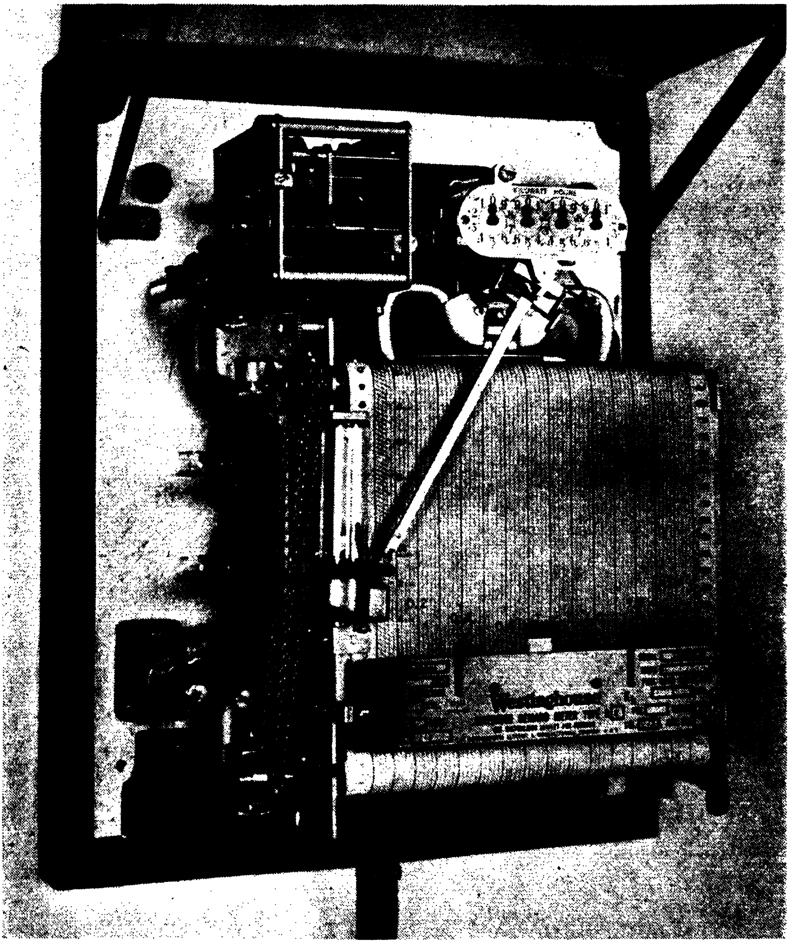


Fig. 16-21. Type R-2 Watthour Recording Demand Meter

The duplex meters consist of two identical but independently operated recording demand meters in one case. The paper-chart mechanisms of the two meters are advanced together by one clock.

The duplex-differential totalizing meters consist of two identical but independently operated recording demand meters in one case. A differential mechanism totalizes both the kw demand and the kwhr of the two meters. The meter provides readings of kw demand and kwhr of one meter and the totalized kw demand and kwhr of both meters.

Type TR-2

The Type TR-2 recording demand meter is similar to the Type R-2 except for the addition of a two-rate kilowatthour register. Type TR-2 meters are furnished in the same types and for the same applications as Type R-2 meters.

Type RI Recording Watthour and Kva Demand Meter

This type is comprised of two identical watthour meters, one of which measures the power component and the other the reactive component by means of an externally connected phase-shifting transformer. The meter contains a ball type differential mechanism arranged to add the motions of the two meter elements vectorially, and thus to drive a gear train in proportion to the kva. Fig. 16-22.

Fig. 16-23 illustrates the principle of the ball mechanism. Two disks are driven by the kvar and kw elements respectively, and they in turn cause the ball to rotate. This motion is transmitted to the driven disk at the top of the ball which is swiveled in jewel bearings to follow the vectorial direction of the surface of the ball. The speed of the driven disk, which is pivoted, corresponds to the power factor of the circuit and by means of a pointer indicates this instantaneous power factor on a scale. The motion of the driven disk is transmitted to an integrating register and to the recording pen.

The meter provides readings of kwhr, kvarh and kvah, a record on one chart of kw and kva demand for each interval, and an indication of power factor. The kva demand record is made by the pen which is driven across the paper in proportion to the total kva of the circuit. The kw demand is obtained by means of a *stop* driven by the kw gear train. At the end of the demand interval,

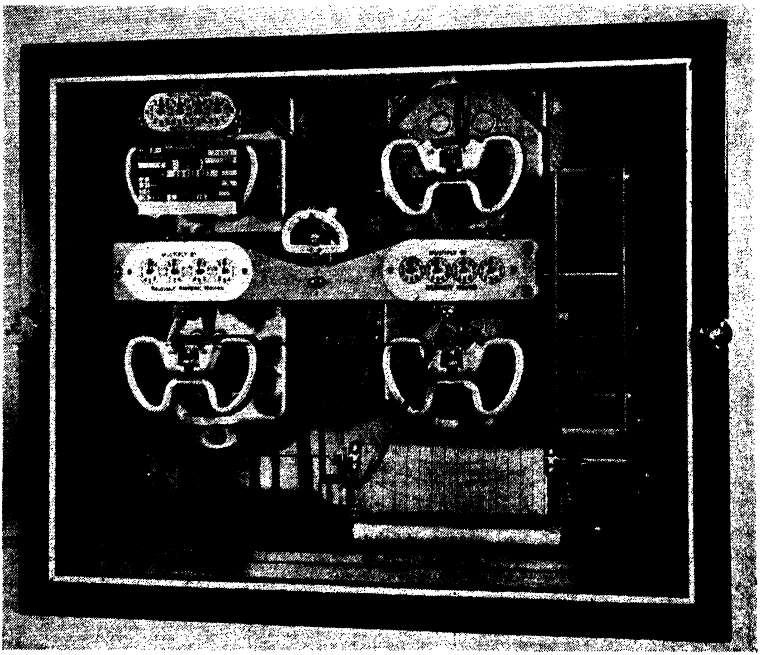


Fig. 16-22. Type RI Watthour and Kva Recording Demand Meter

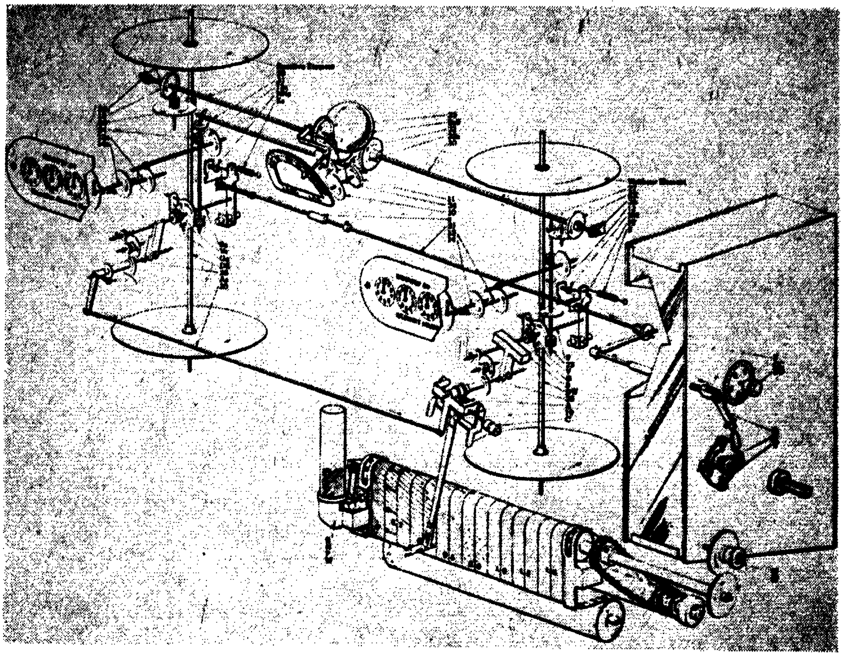


Fig. 16-23. Schematic Operation of RI Watthour and Kva Recording Demand Meter

the pen is disengaged from the kva gears and falls back until arrested by the *stop* where it pauses momentarily and then is reset to zero. Since the paper chart is moving during this *resetting period,* distinct vertical marks are made at both the kva and kw demand points.

The demand interval may be provided by either a 35-day, hand-wound clock, or by a synchronous motor. These are used to determine the demand interval and do not trip the pen or advance the paper. This is done by another hand-wound mechanism.

In later models, the synchronous motor is used to determine the demand interval and to wind up a spring which when tripped by the interval mechanism advances the paper and trips the pen. This unit is interchangeable with the previous one.

Intervals of 15, 30 or 60 minutes are provided. The paper advances one-half inch per hour for the 15- and 30-minute intervals and one-eighth inch per hour for the 60-minute interval. Full scale ratings and chart markings are the same as those of the Type RB. Burden data for the Type RI is given in Table 16-E and constant data in Table 16-W.

Meters in the RI line and their applications are:

Type	*Number of Elements*	*Circuit Application*
RI-2	2	**3-phase, 3-wire** **2-phase, 4-wire**
RI-3	3	**3-phase, 4-wire**
RI-4	3	**Totalizing** **1-phase, 2-wire and** **3-phase, 3-wire**

Type	*Number of Elements*	*Circuit Application*
RI-6	3	Totalizing 1-phase, 3-wire and 3-phase, 3-wire
RI-7	2	3-phase, 4-wire, delta
RI-8	2½ Split Coil	3-phase, 4-wire, wye
RI-9	3	3-phase, 4-wire, delta
RI-10	2	2-phase, 5-wire
RI-32	4	Totalizing 3-phase, 3-wire or 2-phase, 4-wire
RI-38	4 Split Coil	Totalizing 3-phase, 4-wire, wye

INDICATING KVA DEMAND METERS

Type RK Indicating Kva Demand Meter

This type, Fig. 16-24, is similar in operation to the Type RI meter except for the substitution of a demand register for the recording mechanism. A similar device is used as in the Type RI to add the power and reactive component. A synchronous motor is used to provide the demand interval. The phase-shifting transformers are mounted within the meter making a self-contained unit.

Type RK meters for single-phase applications are mounted in a three-element watthour meter case of the A type. The register indicates kilowatthours and cumulative kva demand.

The polyphase RK meters are provided with an internal switch to facilitate testing. In the test position the phase shifting transformers are disconnected and the potential coils of the left-hand elements are connected in parallel with the corresponding right-hand elements.

Polyphase RK meters may be supplied with any of the following registers:

1. Kilowatthour dials and cumulative kilovolt-ampere demand dials.
2. Kilowatthour dials and a sweep-hand kilovolt-ampere demand scale.
3. Kilowatthour dials, kilovolt-ampere-hour dials and a sweep-hand kilovolt-ampere demand scale.

The types of meters in the RK line and their applications are:

Type	*Number of Elements*	*Circuit Application*
RKA	1	1-phase, 2 or 3-wire
RK-2	2	3-phase, 3-wire 2-phase, 4-wire
RK-3	3	3-phase, 4-wire
RK-4	3	Totalizing 1-phase, 2-wire and 3-phase, 3-wire
RK-5	2	3-wire, network 1-phase, 3-wire
RK-6	3	Totalizing 1-phase, 2-wire and 3-phase, 3-wire
RK-7	2	3-phase, 4-wire, delta
RK-8	2½ Split Coil	3-phase, 4-wire, wye
RK-9	3	3-phase, 4-wire, delta
RK-10	2	2-phase, 5-wire, delta

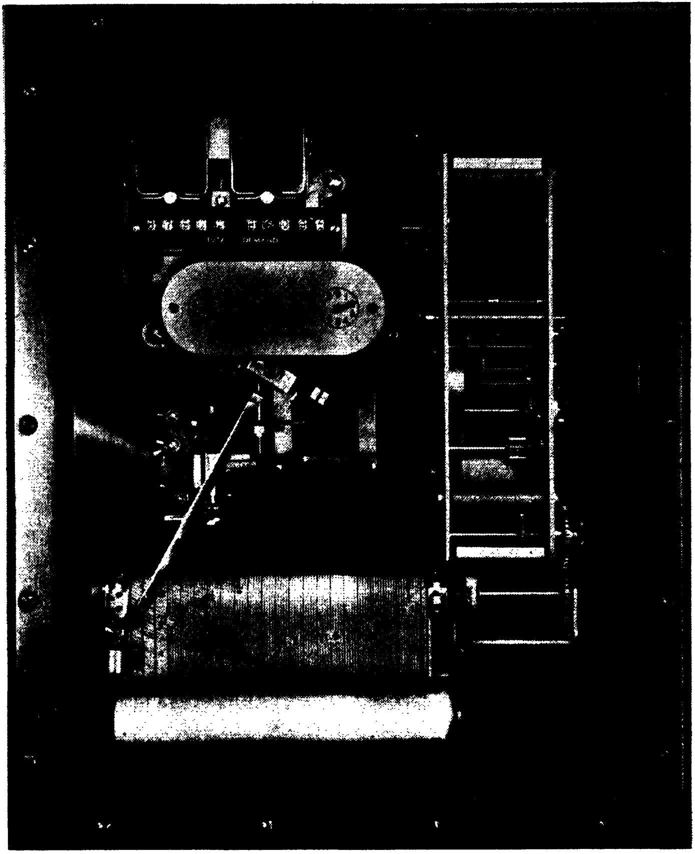


Fig. 16-24. Type RK-2 Indicating Kva Demand Meter

Type RKD Kva Impulse Transmitters

The Type RKD meters are similar to the Type RK meters except that the demand mechanism is replaced by a contact device for transmitting kva impulses. These kva impulses may operate any of the impulse demand meters. Only kilowatthour dials are provided.

Type RKD meters are furnished in the same types and for the same applications as are the polyphase RK meters.

Totalization of impulses from RKD meters in several circuits gives the arithmetic sum of the kva values of the individual circuits.

TYPE WA CONTACT-OPERATED INDICATING DEMAND METER

This meter is used in conjunction with one or more watthour meters equipped with contact devices to indicate the maximum kilowatt demand by means of a friction pointer and scale. It is of the block interval type, integrating the demand over a definite demand interval. Fig. 16-25.

The contact device in each watthour meter is connected in series with the operating relay in the demand meter. The design of the Type QD contact device and the high-speed notching relay in the receiving unit minimizes the probable error due to simultaneous occurrence of impulses.

The limitations of resistance and

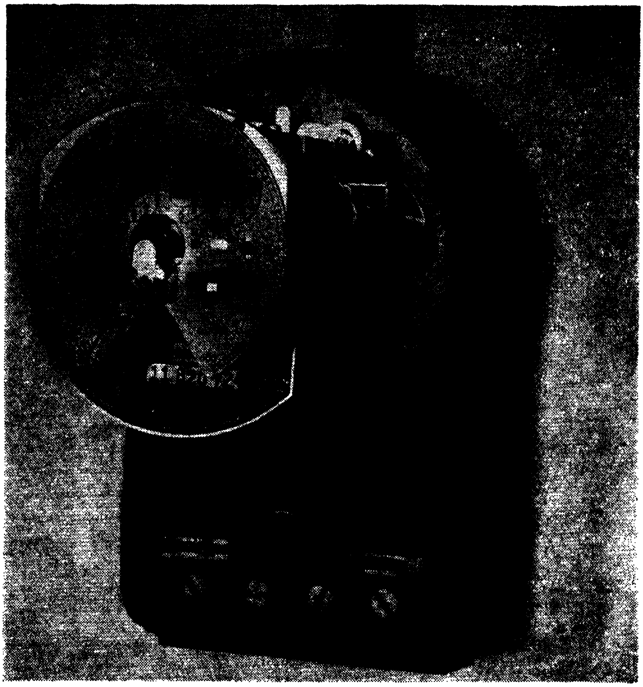


Fig. 16-25. Type WA-2 Contact-Operated Demand Meter

capacity of the impulse transmission wires will, under ordinary conditions, permit the use of at least one mile loop telephone cable with #22 wires. In general, the transmission channels should not exceed approximately 300 ohms, and the capacity should not exceed approximately .075 microfarads. Only contact devices of special design can be used with this meter.

Operating Principle — Electrical impulses transmitted from the watthour meters at a rate proportional to the load momentarily open the circuit of the notching relay which is normally closed. The opening of the circuit causes the relay to notch, and on closing causes it to drive the kw pointer forward by means of suitable gearing. In order to obtain high speed action of the notching relay, direct current is supplied from a rectifier. The Type QD contact devices are designed for use with this meter.

A synchronous motor provides the demand interval and returns the pusher pointer to zero, leaving the maximum demand pointer at the maximum reading until manually reset.

Types of meters in the WA line are:

Type	*Register Readings*
WA-1	Indicated demand
WA-2	Indicated demand and kilowatthours
WA-3	Cumulated demand and kilowatthours

Type WRA or RA Impulse Recording Demand Meter

This meter is impulse operated, designed to totalize the integrated energy of two separate circuits and provide a graphic record of the block interval demand. Fig. 16-26.

When more than two circuits are to be totalized, Type RT impulse totalizing relays should be used. These relays receive and totalize impulses from the watthour meters or kva impulse transmitters and send impulses to operate the Type WRA meter. Both the WRA meter and the RT relay operate from three-wire contact devices.

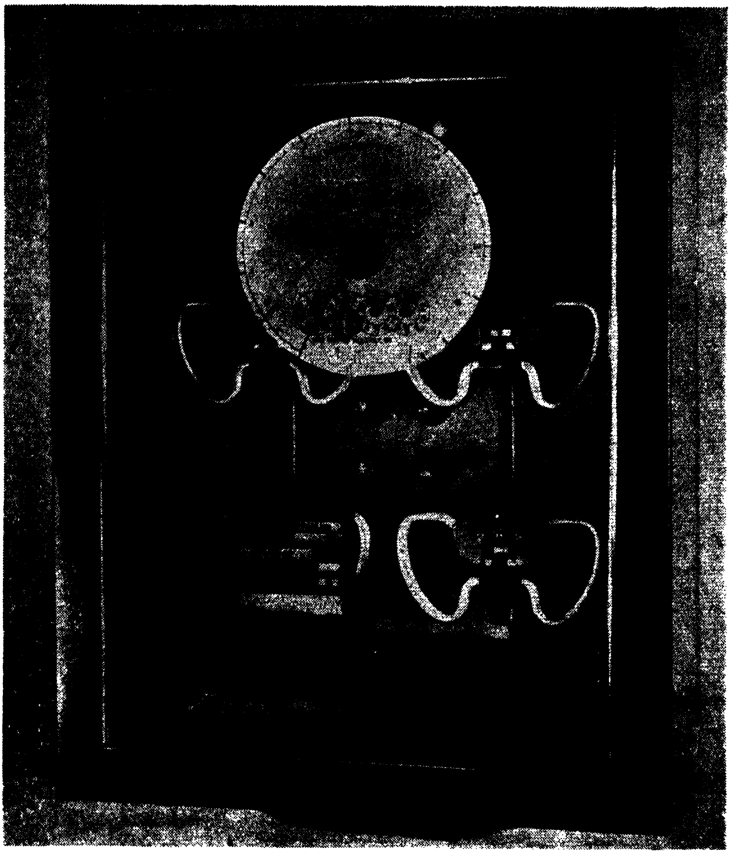


Fig. 16-26. Type WRA Impulse Recording Demand Meter

Principle of Operation—Two operating elements for each circuit receive the impulses alternately and exert a pull on the opposite ends of a pivoted armature. The armature oscillates in synchronism with the opening and closing of the three-wire contact devices used to send the impulses from watthour meters or RT relays.

These armature oscillations allow an escapement wheel to advance, which controls one side of a differential gearing. The other side is controlled by the escapement wheel of the second armature. The differential has a turning effort impressed on it by means of a spring which is in turn wound by a constantly excited torque motor. Registration of simultaneous impulses is assured by the differential mechanism. The differential is geared to operate the total kilowatthour register dials, and the demand recording pen.

Individual impulse counters are mounted on each element. The registering and recording mechanisms are the same as for the standard RA recording demand meters. These meters may be provided also with retransmitting contacts if further totalization is desired.

Type WRI Kva Impulse Operated Receiver

The Type WRI impulse operated kva receiver is similar to the Type RI-2 except that each meter element is replaced by an impulse operated relay. Watthour and varhour impulses are received from watthour and varhour meters equipped with three-wire contact devices. The kva of two circuits may be totalized. The impulse mechanism is similar to that in the Type WRA. The register of the Type WRI meter is mechanically the same as for the RI-2 meter. The kva demand recorded is the vector sum of the kva values of the circuits involved. When more than two circuits are to be totalized, separate RT relays must be used in the kw and kvar circuits.

CONTACT DEVICES, TYPES CD-2, CD-3, AND QD

These contact devices are for use on watthour meters to advance the registering mechanism of contact-operated demand meters or totalizing relays. They transmit low-value current impulses at a rate directly proportional to the value of the energy being measured by the integrating meters.

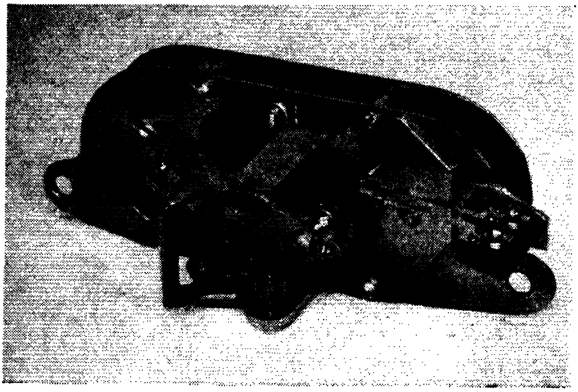


Fig. 16-27. Type CD-2 Contact Device, Register Mounted Type

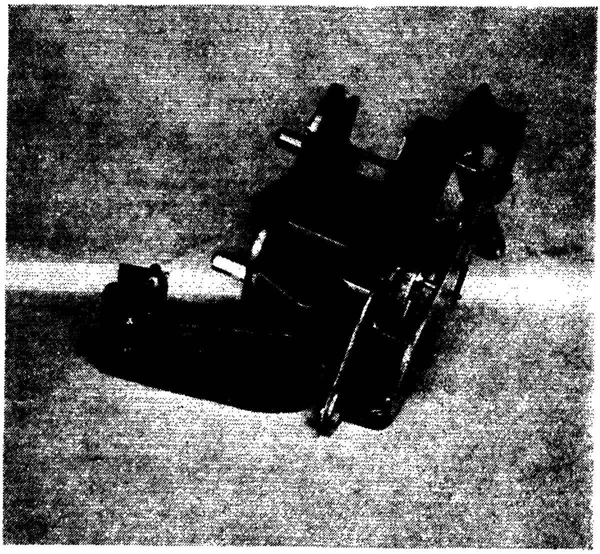


Fig. 16-28. Type CD-3 Contact Device, Register Mounted Type

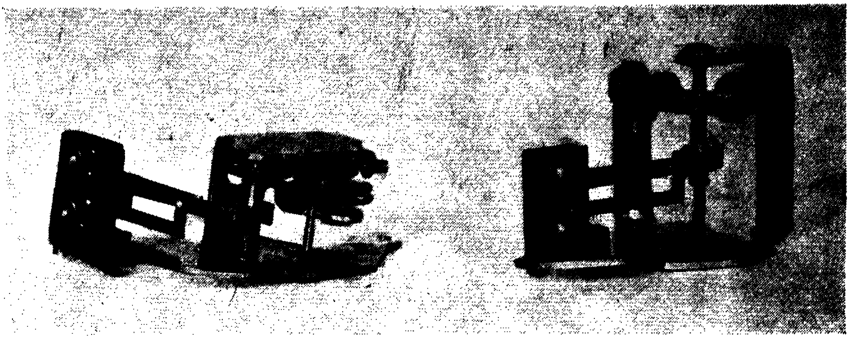


Fig. 16-29. Type QD Contact Device, Shaft Mounted Type

The Type CD-2, Fig. 16-27, operates on the two-wire or single-circuit principle. The Type CD-3, Fig. 16-28, operates on the three-wire or double-circuit principle. The Type QD, Fig. 16-29, is a two-wire contact device, but differs from the Type CD-2 in that the contact points are kept normally closed except for a very short period, approximately 1/25 second, for each cycle of operation. It is designed for operating the WA impulse demand meter.

A ratchet protects the contact device in case of reverse rotation of the watthour meter.

The brackets for all frame mounting types and for the register mounting types for Types C and OA meters are one-piece construction. All other register mounting types are two-piece construction and can be adjusted for mounting in the register of any of the single-phase or polyphase OB or later designed meters. In addition to the ordinary type of mounting in which the contact device is driven from a pinion on the disk shaft of the meter, each type is available in a type of bracket which can be mounted in the standard register of all meters except those manufactured before the Type OA, without modification of the register. See Figs. 16-27 and 16-28.

DEMAND CONSTANT

When demand meters are equipped with arbitrarily calibrated scales, and are operated from contact devices, it is necessary to multiply the demand meter reading by a demand constant.

The value of the demand constant depends upon the type of meter, its rating, and upon the type of contact device, number of points on the cams, ratio of disk revolutions to cam shaft, demand interval, and upon the type of demand meter.

If the bracket ratio and number of teeth on the cams are known, the kilowatthours per impulse may be determined as follows:

$$\text{Kilowatthours per impulse} = \frac{K_h \times R}{N \times 1000}$$

K_h = watthours per revolution of the disk (marked on nameplate)

R = revolutions of watthour-meter disk to one revolution of cam shaft. (Stamped on bracket of the attachment and called the bracket ratio)

N = number of teeth on each cam

Impulses per hour at full kw load rating of the meter—

$$\text{I.P.H.} = \frac{1500 \times N}{R}$$

If the kilowatthours per impulse is the known quantity and it is necessary to determine the proper bracket ratio and number of cam teeth on each cam, for a given meter capacity, proceed as follows, bearing in mind to use cams with less than ten teeth if possible and a bracket ratio from Table 16-V.

The kilowatt capacity of the meter is defined as the load which will cause the disk to run 25 rpm = 1500 revolutions per hour.

$$\frac{\text{kw capacity}}{\text{kwhr per impulse}} = \text{impulses per hour/(I.P.H.)}$$

The impulses per hour having been determined, it is only a matter of inspection to determine the number of cam teeth and bracket ratio.

As an example:

kw capacity of meter = 120
kwhr per impulse = 0.5

$$\frac{120}{0.5} = 240 \text{ I.P.H.}$$

It is obvious that six-point cams and a cam shaft 40 revolutions per hour meet this condition.

Referring to Table 16-V a cam shaft making 40 revolutions per hour, requires a bracket ratio of 37½.

TYPE RT IMPULSE TOTALIZING RELAY

This device, shown in Fig. 16-30, will totalize, irrespective of sequence or simultaneous occurrence, the impulses received from three separate three-wire impulse transmitting units and, in turn, transmit a series of impulses equal to or proportional to the total number received.

The number of impulses received by each of the three elements is indicated on separate cyclometer dials. The totalizing relay may be used with any impulse demand meter designed to operate from three-wire contact devices.

Principle of Operation—The receiving elements and differential totalizing mechanisms are similar in construction and operation to those used in the Type WRA impulse recording demand meter, with two principal differences; (1) it has three elements and can thus totalize three circuits and (2) instead of operating a totalizing register, or drawing a record, it controls a set of contacts similar to the contact device of a watthour meter. Fig. 16-31 schematically illustrates the operation of the Type RT relay.

The following ratios of impulses received to impulses transmitted, are available:

1 to 1	5 to 2	3 to 1
5 to 3	3 to 2	15 to 1
5 to 1	2 to 1	

TIME SWITCHES

Type TCS and TCA Combination Watthour Meter and Time Switch

These meters, Figs. 16-32 and 16-33, consist of a single-phase Type

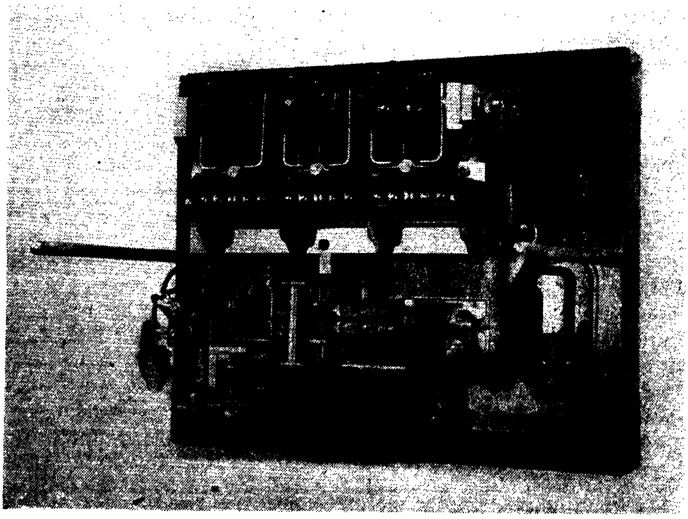


Fig. 16-30. Type RT Impulse Totalizing Relay

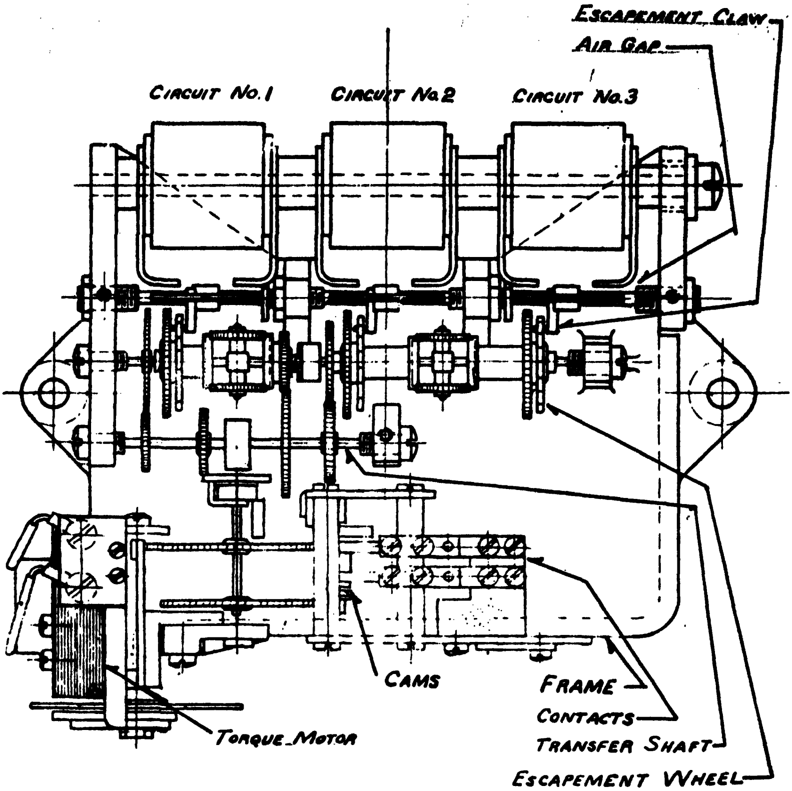


Fig. 16-31. Type RT-Relay—Schematic Diagram of Mechanism

CS or CA watthour meter equipped with a combination register and time switch. They combine in a single unit the watthour meter and the necessary dials, time switch mechanism, and contacts for metering and controlling two-rate and off peak loads. The two-rate register is designed to meter the off peak loads on a separate set of dials. The time switch automatically transfers the registration of the meter from one set of dials to the other at predetermined times, and simultaneously opens or closes an external circuit.

These meters are manufactured in the following standard types in which the A or S denotes type of meter mounting and the numerals denote, respectively, single or double-dial register, single or double-pole, and single or double-throw contacts:

Type TCS 111—TCA 111
Single-dial register, and single-pole, single-throw contacts.
Type TCS 121—TCA 121
Single-dial register, and double-pole, single-throw contacts.
Type TCS 211—TCA 211
Double-dial register, and single-pole, single-throw contacts.
Type TCS 221—TCA 221
Double-dial register, and double-pole, single-throw contacts.
Type TCS 200—TCA 200
Double-dial register—no contacts.

Type TS and TA Time Switch

This time switch is available in the S and A type bases. Fig. 16-34. The switch mechanism is similar to that used in the TCS and TCA meters. Switches are made in the following types:

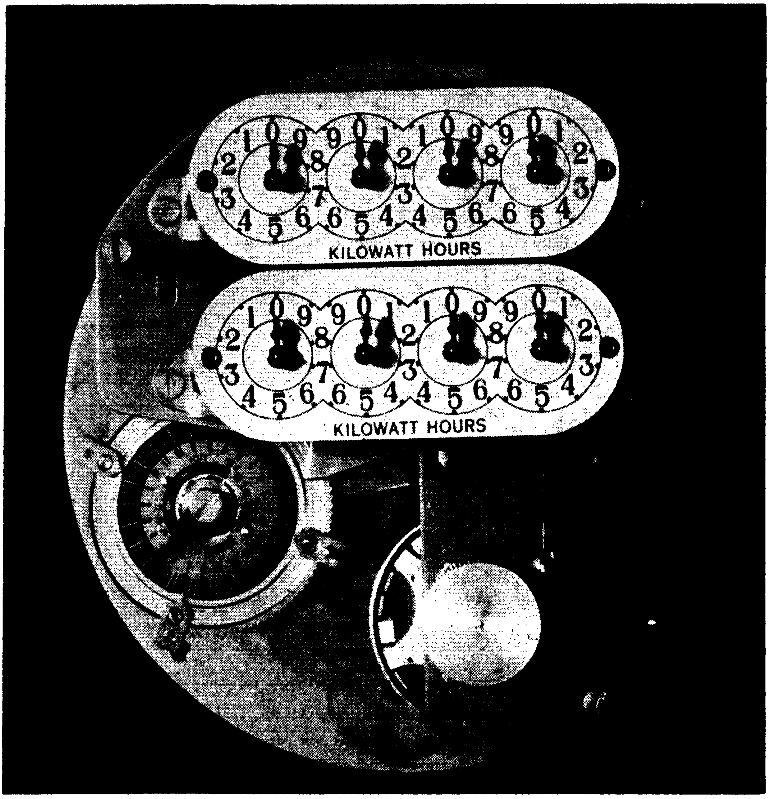


Fig. 16-32. Two-Rate Register and Time Switch

Type TS 11—Single pole, single
TA 11 throw contacts.

Type TS 12—Single pole, double
TA 12 throw contacts.

Type TS 21—Double pole, single
TA 21 throw contacts.

COMBINATION WATTHOUR AND THERMAL DEMAND METER

There are three basic lines of thermal demand meters. The first (Types CAH, CSH, CAH-2, etc.) is a line of combination watthour and thermal watt demand meters; the second (Type KAH) is a thermal kva demand meter of the displaced voltage type; the third (Type QCA) is a combination watthour and ampere demand meter. Kilowatthours are indicated on the combination meters by a standard register. Maximum demand is indicated on all meters by a friction pointer and scale.

Types CAH and CSH Combination Watthour and Thermal Watt Demand Meters

Types CAH and CSH meters combine a conventional watthour meter with a thermal watt demand element. The watthour meter proper is of the standard induction type and its characteristics are unchanged by the action of the associated thermal element.

The thermal element operates on the principle of indirect heating. Three-wire meters are made by using two independent heaters for each bimetallic coil. All meters are manufactured in 5-, 15- and 50-ampere capacities for a demand interval of fifteen minutes.

Full scale values represent 166 2/3 per cent of full load for the 5- and 50-

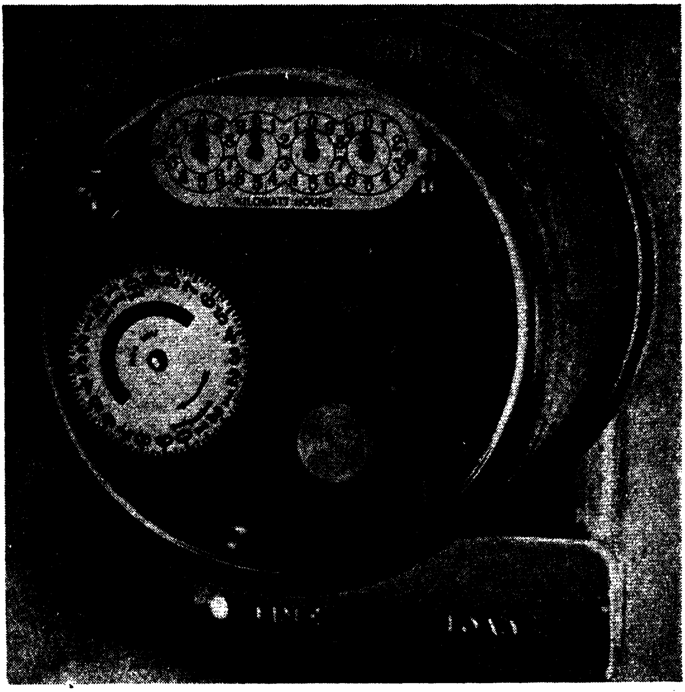


Fig. 16-33. Type TCA-111 Watthour Meter and Time Switch, Single-rate Register Type

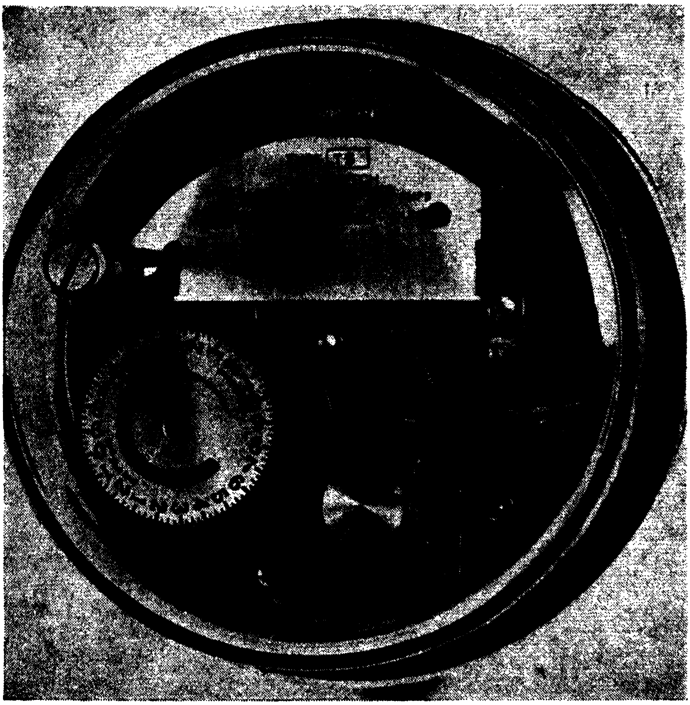


Fig. 16-34. Type TS-11 Time Switch

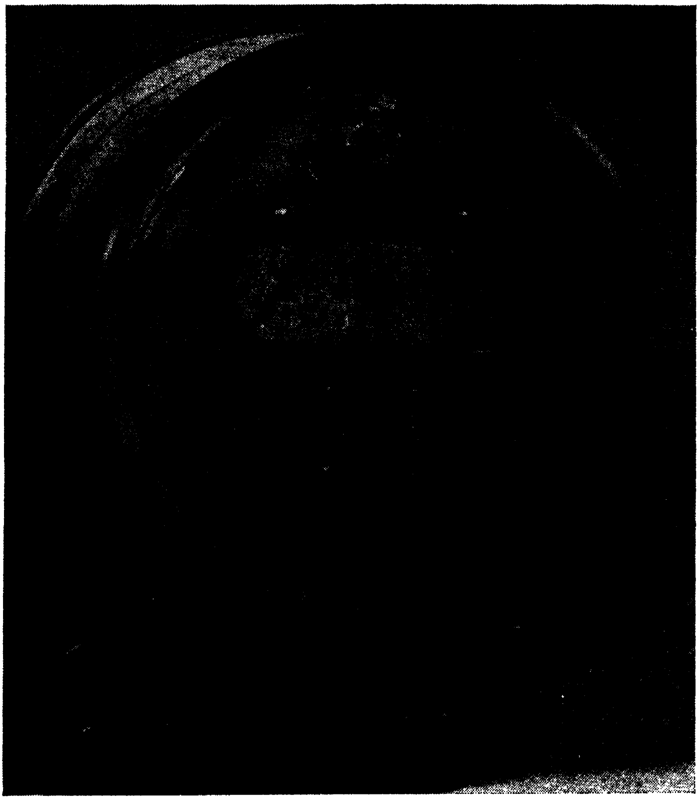


Fig. 16-35. Type CAH Single-phase Combination Watthour and Thermal Demand Meter

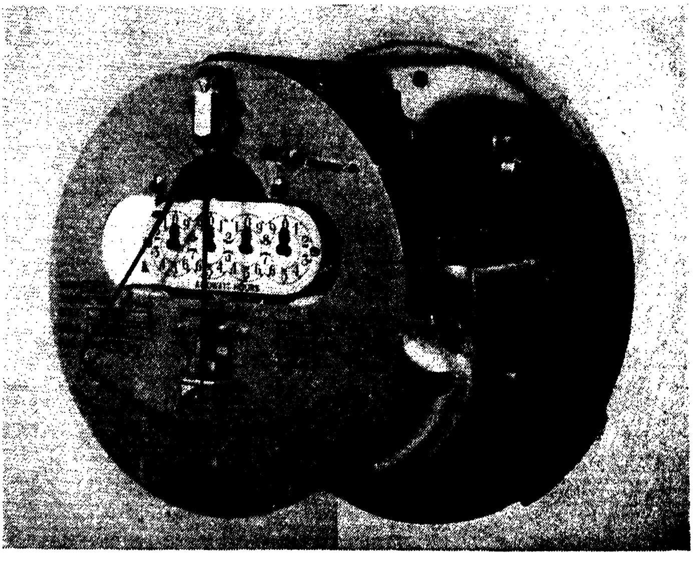


Fig. 16-36. Type CSH Single-phase Combination Watthour and Thermal Demand Meter

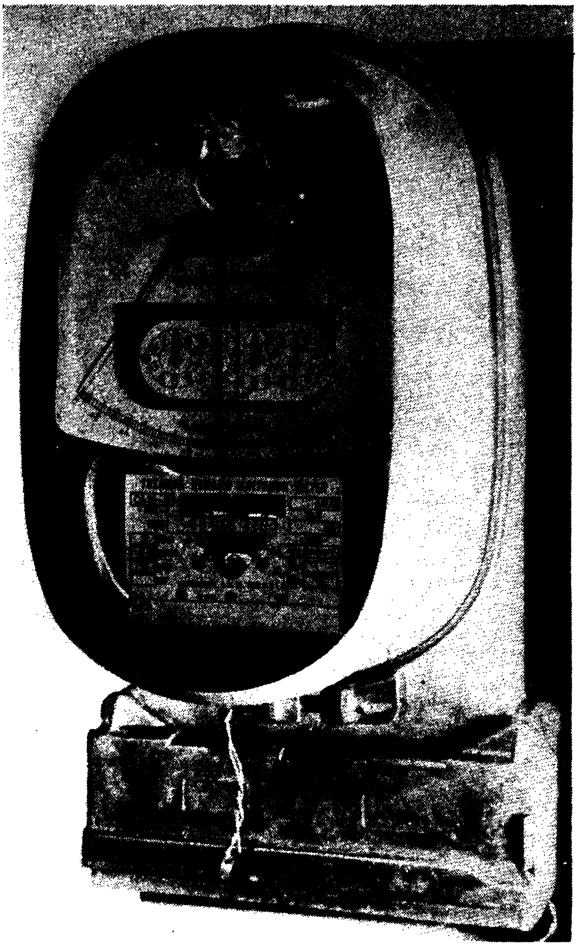


Fig. 16-37. Type CAH-2 Polyphase Combination Watthour and Thermal Demand Meter

ampere meters and 278 per cent for the 15-ampere meters, based on 120 volts or multiples thereof.

Single-phase combination watthour and thermal watt demand meters are manufactured in the Type A and Type S bases. Figs. 16-35 and 16-36. These meters are designated CAH and CSH, respectively. The Type CAH meter is mounted in the CA-5 two-element watthour meter base. Single-phase meters use the electromagnet potential coil as the primary of the potential transformer. The saving in space allows the mounting of the combination meter in a small case. Current transformers are used in the 50-ampere meter. These meters are interchangeable in connections with standard watthour meters of similar types.

The polyphase meter is manufactured in the Type A base only (Fig. 16-37) and is mounted in the CA-3 three-element watthour meter base. Separate potential transformers are used in all polyphase meters and current transformers are used except in the 5- and 15-ampere ratings of the CAH-2. All polyphase meters are in-

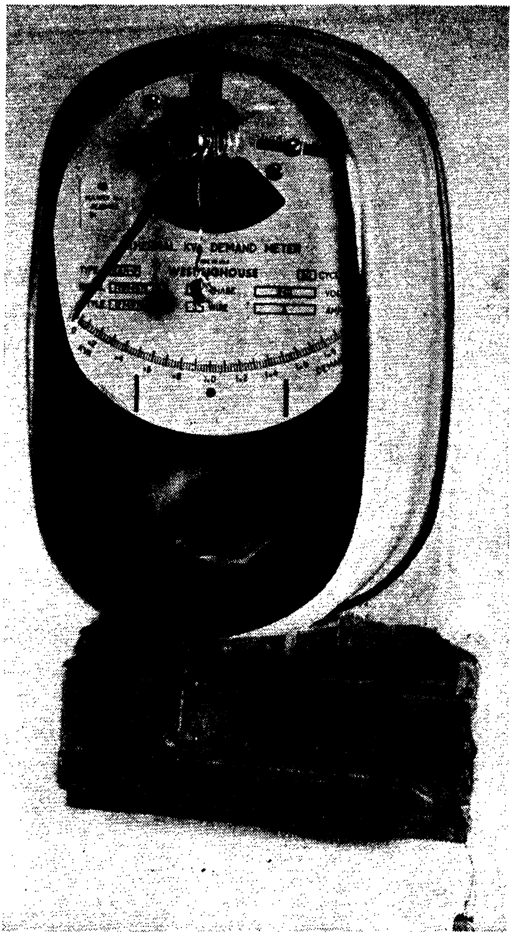


Fig. 16-38. Type KAH-2 Polyphase Thermal Kva Demand Meter

terchangeable in connections with standard watthour meters of similar type.

Combination watthour and thermal watt demand meters and their applications are:

Type	*Number of Elements*	*Circuit Application*
CAH CSH	1	Single-phase, two-wire or single-phase, three-wire
CAH-2	2	Three-phase, three-wire or three-wire network
CAH-7	2	Three-phase, four-wire, delta
CAH-8	2 Split Coil	Three-phase, four-wire, wye

Type KAH Thermal Kva Demand Meter

Type KAH meters measure kva demand of polyphase circuits by the displaced voltage method. Fig. 16-38. These meters are essentially polyphase thermal watt demand meters in which the voltage applied to the thermal unit is shifted, through the use of autotransformers, by an angle approximately equal to the phase angle of the circuit. The angles by which the voltage may be shifted are 0°, 30°, 45° and 60° correspondingly to power factors of 100%, 87%, 71% and 50% as marked on the tap changing panel. The Type KAH meter is mounted in

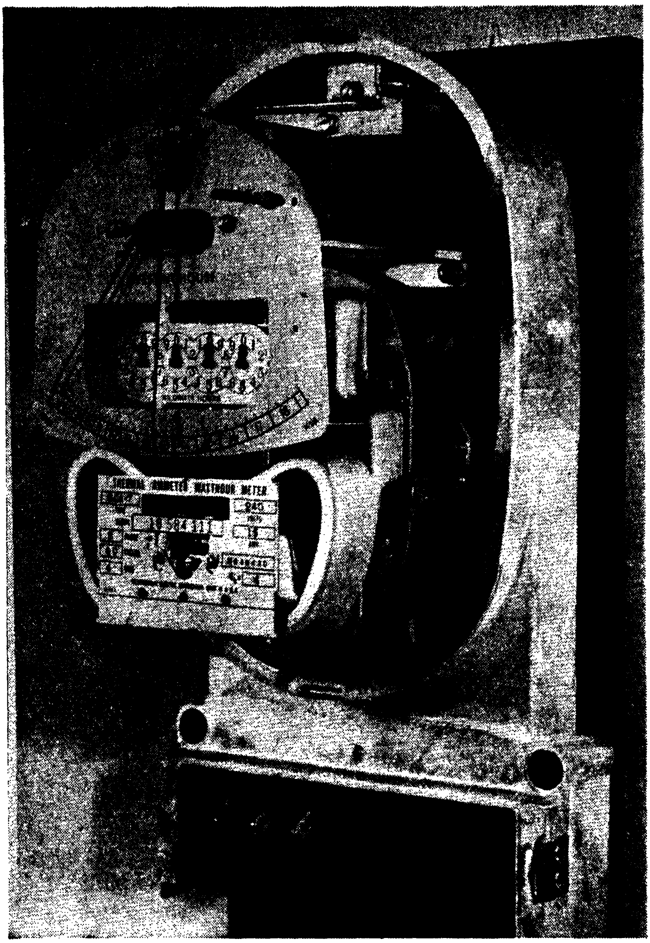


Fig. 16-39. Type QCA-7 Polyphase Combination Watthour Meter and Thermal Ampere Demand Meter

the CA-3 (three-element watthour meter) base and is interchangeable in connections with the standard watthour meters of similar types. Dial markings are similar to those of the thermal watt demand meters.

The types of meters in the KAH line and their applications are:

Type	*Number of Elements*	*Circuit Application*
KAH-2	2	Three-phase, three-wire
KAH-5	2	Three-wire network
KAH-7	2	Three-phase, four-wire delta
KAH-8	2 Split Coil	Three-phase, four-wire wye

Type QCA Combination Watthour Meter and Thermal Ampere Demand Meter

Type QCA meters combine a conventional watthour meter with a thermal ampere demand element. The watthour meter is of the standard type and its characteristics are unchanged by the addition of the thermal element.

Single-Phase Meters — The single-phase thermal ammeter element is similar to that of the watt demand meter except that heaters are associated with only one bimetallic coil. Transformers are used to combine the currents in three-wire, single-phase meters. These meters are mounted in the CA-5 two-element watthour meter base and are interchangeable in connections with watthour meters of similar types.

Polyphase Meters — Polyphase combination watthour and thermal ampere demand meters are mounted in the CA-3 three-element watthour meter base. The use of current transformers in all meters allows simplification of the circuit and standardization between types. These meters are interchangeable in connections with standard watthour meters of similar types. Fig. 16-39.

The types of meters in the QCA line and their applications are:

Type	*Number of Elements*	*Circuit Application*
QCA	1	Single-phase, two-wire or single-phase, three-wire
QCA-2	2	Three-phase, three-wire
QCA-5	2	Three-wire network
QCA-7	2	Three-phase, four-wire delta
QCA-8	2 Split Coil	Three-phase, four-wire wye

DIRECTIONS FOR USE OF TABLES

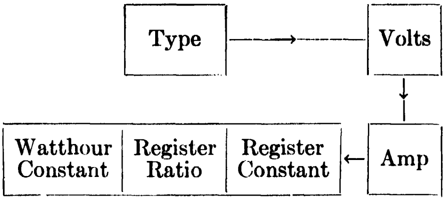
The following tables list certain information with respect to detailed data, constants and register data for Westinghouse meters.

Tables 16-A to 16-E inclusive tabulate certain detailed data.

Constants and register data for each ampere size d-c meter are given in Table 16-F and for each a-c meter in Table 16-H for the types shown in Table 16-G.

Constant and register data for all Westinghouse instrument transformer meters, based on their nominal kw rating, are given in Table 16-L, supplemented by Tables 16-I, 16-J, and 16-K. These tables may also be used for the self-contained meters as well, if the rating of the meter is in terms of its kw capacity.

Constant Table 16-F is for d-c watthour meters. This table and some of the following tables are used by indexing from the proper type over to the right voltage, then down to the ampere rating and from there on the same horizontal line over to the corresponding constant data.



Key for Constants Tables

Tables 16-G and 16-H give the watthour constant, register constant, register ratio and gear ratio of all Westinghouse a-c self-contained meters except for the Type C metal and glass cover switchboard meters. The operation of these tables is similar to that of the d-c table, the meter type for a certain voltage being selected from Table 16-G which will refer to a certain column of Table 16-H for the constants and register data.

Table 16-L is a tabulation of all constants and ratios used in registers on Westinghouse self-contained and instrument transformer meters. To use this table, it is necessary to know the nominal kw rating of the meter in question which can be found by applying one of the formulas in Table 16-J. Table 16-K shows the method of obtaining the constants and register data from Table 16-L.

Tables 16-M to 16-Q inclusive cover the constants and register data for all Westinghouse Type C metal and glass cover watthour meters, single and polyphase switchboard type.

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WESTINGHOUSE ELECTRIC METERS

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TABLE 16-A
METER DATA
WESTINGHOUSE DIRECT-CURRENT METERS

Type	First Mfd. (Year)	Full-Load Speed (rpm)	Full-Load Torque (mmg)	Weight of Moving Element (grams)	Ratio of Torque to Weight	Potential Coil				Current Coil at Rated Current (Amp. Turns)	Temp. Coefficient per °C	Overload Capacity (%)
						No. of Turns	Resistance (ohms)	Res. per 100 Volts (ohms)	Loss at 100 Volts (Watts)			
DC-Plain and Sub A	1906	25	140–175	80–90	1.85	800	600	2500	3.5–4.5	600	0.09–0.12	50
CW-6	1912	(a)	140–170	80–95	1.7	1500(b)	1500(b)	2300	4–5		0.09–0.13	50

(a) The full load speed depends upon the rating of the meter in question, and may be determined from the constant marked on the disk.
(b) The potential circuit coil of this type meter consists of 1,500 active turns and 400 inactive turns of copper wire having a resistance of 1,500 ohms.

TABLE 16-B
CURRENT COIL DATA
FOR WESTINGHOUSE DIRECT-CURRENT METERS

Rating in Amperes	Two-wire Meters—Average Limits of Current Coils		Three-wire Meters—Average Limits of Current Coils	
	Drop in Volts	Loss in Watts	Drop in Volts	Loss in Watts
5	1.4 –1.56	7.0– 7.8	0.7 –0.78	7.0– 7.8
7½	0.6 –0.73	4.5– 5.5	0.3 –0.39	4.5– 5.5
10	0.5 –0.6	5.0– 6.0	0.25 –0.30	5.0– 6.0
15	0.3 –0.37	4.5– 5.5	0.15 –0.185	4.5– 5.5
25	0.2 –0.24	5.0– 6.0	0.10 –0.12	5.0– 6.0
50	0.11 –0.13	5.5– 6.5	0.05 –0.06	5.0– 6.0
75	0.067–0.08	5.0– 6.0	0.046 –0.053	7.0– 8.0
100	0.050–0.06	5.0– 6.0	0.042 –0.048	8.5– 9.5
150	0.046–0.053	7.0– 8.0	0.028 –0.032	8.5– 9.5
200	0.040–0.048	8.0– 9.5	0.0225–0.025	9.0–10.0
300	0.026–0.032	8.0– 9.5	0.021–0.025	13.0–15.0
450	0.024–0.029	11.0–13.0		

TABLE 16-C
CURRENT COIL DATA
FOR WESTINGHOUSE TYPE CW-6 DIRECT-CURRENT METERS

Rating in Amperes	Two-wire Meters—Average Limits of Current Coil Circuit		Three-wire Meters—Average Limits of Current Coil Circuit	
	Drop in Volts	Loss in Watts	Drop in Volts	Loss in Watts
5	1.0 –1.14	5.0–5.7	0.5 –0.57	5.0–5.7
10	0.5 –0.57	5.0–5.7	0.25 –0.285	5.0–5.7
15	0.38–0.44	5.8–6.6	0.19 –0.22	5.8–6.6
25	0.22–0.25	5.5–6.3	0.11 –0.125	5.5–6.3
50	0.11–0.125	5.5–6.3	0.055–0.0625	5.5–6.3

TABLE 16-D

METER DATA

WESTINGHOUSE SINGLE-PHASE AND POLYPHASE METERS

Type	First Mfd. (Year)	Full Load Torque per Element (mmg)	Weight of Moving Element (per Element) (grams)	Ratio of Torque to Weight	Loss per Pot. Coil at rated Voltage (Watts)	Loss per Current Coil at Rated Current (5 Amp. Basis) (Watts)	Power Factor of Pot. Coil (%)	Starting Watts per Element (5A. 120V Basis) (Watts)	Range of Full Load Adjustments (%)	Range of Light Adjustments (%)
Round	1898	11-13	15-16	0.77	1.5-1.8	0.9 -1.1	27-30			
A	1903	11-13	15-16	0.77	1.8-2.1	0.9 -1.1	27-30			
B	1906	23-26	15-16	1.58	2.5-2.8	0.7 -0.9	18-20			
B Prepayment		23-26	15-16	1.38	2.5-2.8	0.7 -0.9	18-20			
C	1906	42-46	15-16	2.8	1.5-1.8	0.7 -1.0	16-18			
OA, Plain and Sub A	1910	37-44	15-16	2.6	1.4-1.8	0.65-0.85	15-19			
OA, Sub B, C, D, E, F, and G	1914	44-48	15-16	2.95	1.2-1.5	0.65-0.85	12.5-15			
OA Prepayment	1914	37-44	15-16	2.6	1.4-1.8	0.65-0.85	15-19			
RO Demand (Kwhr Element)		48-50	15-16	3.1	3.3-3.6	0.75-1.0	20-22			
OB Below Serial No. 10,625,000	1924	36	14	2.6	1.1*	0.26	15	1.5	80-120	85-120
OB Above Serial No. 10,625,000	1928	33	14	2.4	1.1*	0.26	15	1.5	80-120	85-120
OC, CA and CS, Below Serial No. 15,000,000	1932	40	13	3.0	1.5	0.22	15	1.5	80-120	85-120
CA, CB, CB-F, CS, TCA, TCS and OC above Serial No. 15,000,000	1937	48	16	3.0	1.5	0.18	15	1.5	80-120	85-120
C-2, 5, 7, 8 and 10	1934	40	13.5	3.0	2.0*	0.26	16	1.5	80-120	85-120
C-3, 4, 6, 9	1935	40	15.5	2.6	2.0*	0.26	16	1.5	80-120	85-120
CA-2, 3, 5, 7, 8, 9 and 10, CS-2, 3, 5, 7, 8, 9 and 10 below Serial No. 15,000,000	1935	33	13.5	2.4	1.1*	0.26	15	1.5	80-120	85-120
CB-2, 3, 5, 7, 8, 9 and 10, below Serial No. 15,000,000	1937	33	13.5	2.4	1.1*	0.26	15	1.5	80-120	85-120
CA-2, 3, 4, 5, 6, 7, 8, 9 and 10, CS-2, 3, 4, 5, 6, 7, 8, 9 and 10, CB-2, 3, 4, 6, 7, 8, 9, 10, 32 and 38, above Serial No. 15,000,000	1938	36	13.5	2.7	1.5*	0.16	18	1.5	80-120	85-120
CB-2F, 3F, 4F, 6F, 7F, 8F, 9F, 10F, 32F and 38F	1943	36	13.5	2.7	1.5*	0.16	18	1.5	80-120	85-120
CAH and CSH	1941	48	16	3.0	4.3**	1.16**	46**	1.5	80-120	85-120
CAH-2, 7, 8	1946	36	13.5	2.7	4.0**	0.78**	83**	1.5	80-120	85-120
KAH-2, 5, 7 and 8	1945				2.0**	0.59**	69**			
QCA	1946	48	16	3.0	1.5*	1.5**	15	1.5	80-120	85-120
QCA-2, 5, 7 and 8	1946	36	13.5	2.7	1.5*	0.62**	18	1.5	80-120	85-120
R-2, 7, 8, 10, 22, 27, 28 and 42	1937	40	13.5	3.0	2.0*	0.26	16	1.5	80-120	85-120
R-3, 4, 6, 9, 23, 29 and 43	1937	40	15.5	2.6	2.0*	0.26	16	1.5	80-120	85-120
R-32, R-52	1942	36	13.5	2.7	1.5*	0.16	18	1.5	80-120	85-120
RI-2, 7, 8 and 10	1938	40	13.5	3.0	+	0.26	+	1.5	80-120	85-120
RI-3, 4, 6 and 9	1938	40	15.5	2.6	+	0.26	+	1.5	80-120	85-120
RI-32, RI-38	1938	36	13.5	2.7	+	0.16	+	1.5	80-120	85-120
RKA Upper Element RKA Lower Element	1940	48	16	3.0	9.6 1.5	0.18 0.18	99 15	1.5	80-120	85-120
RK-2, 5, 7, 8 and 10	1938	84	47	1.8	+	0.26	+	1.5	80-120	85-120
RK-3, 4, 6 and 9	1938	84	51.5	1.6	+	0.26	+	1.5	80-120	85-120
XCA and XCS	1940	48	16	3.0	9.6	0.18	99	1.5	80-120	85-120

* Based upon 120 volts or multiple thereof. Add 15% of given loss when potential indicating lamps are used.

** Includes thermal circuit.

+ See Table 16-E for burden data.

TABLE 16-E

BURDEN DATA

TYPE RI AND RK METER

Values given are for a single element at rated current and voltage (120 volt 5-ampere basis)

	Volt Amperes	Watts	Vars	% P.F.
RI-2, RI-3, RI-4, RI-6, RI-7, RI-8, RI-9, RI-10, RK-2, RK-3, RK-4, RK-5, RK-6, RK-7, RK-8, RK-9, RK-10				
Current Coil	0.59	0.26	0.53	44
Potential Coil (kw side)	13.8	2.5	13.5	18
Potential Coil (kvar side of RI-2 meter, including K-3 phase-shifting transformer)**				
Lagging phase†	23.7	−11.8	20.3	−50‡
Leading phase†	23.7	19.4	14.5	82
Potential Coil (kvar side of RI-8 meter, including K-5 phase-shifting transformer)**				
Lagging phase††	29.8	20.9	21.2	77
Leading phase††	28.9	−10.3‡	27.0	−38‡
RI-32, RI-38 Meters				
Current Coil	0.59	0.26	0.53	44
Potential Coil	9.2	1.9	9.0	20
Potential Coil (kvar side of RI-32 meter, including K-3 phase-shifting transformer)**				
Lagging phase†	16.7	−7.2‡	15.1	−43‡
Leading phase†	17.3	13.6	10.7	79
Potential Coil (kvar side of RI-38 meter, including K-5 phase-shifting transformer)**				
Lagging phase††	23.0	15.1	17.4	66
Leading phase††	22.5	−5.7‡	21.8	−25‡
Phase Shifting Transformers				
K-3, K-4, K-7, K-9 Phase Shifting Transformer (Each Coil*)	4.1	1.3	3.9	31
K-5 Phase Shifting Transformer (Each Coil*)	11.0	2.8	10.6	25

* K-3, K-5, K-7, K-9 transformers use two coils, the K-4 uses three coils.

** For Potential coils on the kvar side of other meters, except those listed above.
W, total watts = potential coil watts + transformer coil watts
V, total vars = potential coil vars + transformer coil vars
Volt amperes = $\sqrt{W2 + V2}$

† If phase rotation is 1–2–3 then phase 1–2 lags phase 3–2 by 60° and is therefore called the lagging phase and conversely phase 3–2 is called the leading phase.

‡ The − sign indicates that power is being fed back to the potential transformer.

†† If phase rotation is 1–2–3 than phase 1–0 lags phase 3–0 by 120° and is therefore called the lagging phase. Conversely phase 3–0 is called the leading phase.

TABLE 16-F
CONSTANTS AND REGISTER RATIO DATA
FOR WESTINGHOUSE D-C WATTHOUR METERS

Type				VOLTAGE							
D-C, Plain, 2-Wire				100		500					
D-C, Plain, 2- or 3-Wire					200						
D-C, Sub A, 2-Wire									500		
D-C, Sub A, 2- or 3-Wire							100	200			
CW-6, 2-Wire										100–110	
CW-6, 2- or 3-Wire											200–220
Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	Gear Ratio (R_g)	AMPERE RATING							
1/3	4796 3/5	1	29978 3/4	5							
1/2	3200	1	20000	7 1/2							
2/3	2400	1	15000	10	5						
1	1600	1	10000	15	7 1/2						
1 1/3	1200	1	7500		10						
1 2/3	960	1	6000	25		5					
2	800	1	5000		15						
3 1/3	480	1	3000	50	25	10					
5	320	1	2000	75		15					
6 2/3	240	1	1500	100	50						
8 1/3	192	1	1200			25					
10	160	1	1000		75						
13 1/3	120	1	750		100						
16 2/3	960	10	6000			50					
33 1/3	480	10	3000			100					
1/3	6000	1	30000				5				
1/2	4000	1	20000				7 1/2				
2/3	3000	1	15000				10	5			
1	2000	1	10000				15	7 1/2			
1 1/3	1500	1	7500					10			
1 2/3	1200	1	6000				25		5		
2	1000	1	5000					15			
2 1/2	800	1	4000						7 1/2		
3 1/3	600	1	3000				50	25	10		
5	400	1	2000				75		15		
6 2/3	300	1	1500				100	50			
8 1/3	240	1	1200						25		
10	200	1	1000				150	75			
13 1/3	150	1	750				200	100			
16 2/3	1200	10	6000						50		
20	1000	10	5000				300	150			
25	800	10	4000						75		
26 2/3	750	10	3750					200			
30	666 2/3	10	3333 1/3				450				
33 1/3	600	10	3000						100		
40	500	10	2500					300			
50	400	10	2000						150		
60	333 1/3	10	1666 2/3					450			
66 2/3	300	10	1500						200		
100	200	10	1000						300		
150	1333 1/3	100	6666 2/3						450		
1/5	500	1	50000							5	
2/5	250	1	25000							10	5
3/5	166 2/3	1	16666 2/3							15	
4/5	125	1	12500								10
1	100	1	10000							25	
1 1/5	83 1/3	1	8333 1/3								15
2	50	1	5000							50	25
4	25	1	2500								50

TABLE

WESTINGHOUSE A-C

FOR WHICH THE CONSTANTS

SINGLE-PHASE METERS ARE GIVEN IN

Type	Frequency (Cycles)	Rating	Remarks	See Table 16-H Column No.
Round	25–140	100 Volt, 2-Wire		1
		200 Volt, 2-Wire 100–200 Volt, 3-Wire		7
		400 Volt, 2-Wire 200–400 Volt, 3-Wire		14
A	25–140	100 Volt, 2-Wire		1
		200 Volt, 2-Wire 100–200 Volt, 3-Wire		7
		400 Volt, 2-Wire 200–400 Volt, 3-Wire		14
B	25–140	100 Volt, 2-Wire	Serial No. 418,000 (approx.) and below	5
			Above Serial No. 418,000 (approx.)	4
		200 Volt, 2-Wire 100–200 Volt, 3-Wire	Serial No. 418,000 (approx.) and below	12
			Above Serial No. 418,000 (approx.)	11
		400 Volt, 2-Wire 200–400 Volt, 3-Wire	Serial No. 418,000 (approx.) and below	22
			Above Serial No. 418,000 (approx.)	20
B Prepayment	25–140	100 Volt, 2-Wire		3
		200 Volt, 2-Wire 100–200 Volt, 3-Wire		11
C	25–140	100 Volt, 2-Wire	Below Serial No. 158,000 (approx.)	4
			Serial No. 158,000 and above	3
		200 Volt, 2-Wire 100–200 Volt, 3-Wire		11
		400 Volt, 2-Wire 200–400 Volt, 3-Wire		20
		500 Volt, 2-Wire		26
OA	25–140	100 Volt, 2-Wire	Below Serial No. 886,453 (approx.)	8
		200 Volt, 2-Wire 100–200 Volt, 3-Wire	Below Serial No. 886,453 (approx.)	15
OA Sub A	24–140	100 Volt, 2-Wire	Above Serial No. 886,453 (approx.)	3
		200 Volt, 2-Wire 100–200 Volt, 3-Wire	Above Serial No. 886,453 (approx.)	11
		400 Volt, 2-Wire	Above Serial No. 886,453 (approx.)	20
OA Sub B, C, D, E & F	25–140	100 Volt, 2-Wire		3
		200 Volt, 2-Wire 100–200 Volt, 3-Wire		11
		400 Volt, 2-Wire		21
		500 Volt, 2-Wire		27
OA Prepayment	25–140	100 Volt, 2-Wire		3
		200 Volt, 2-Wire 100–200 Volt, 3-Wire		11
OB	25, 50 & 60	120 Volt, 2-Wire		6
		240 Volt, 2-Wire 120–240 Volt, 3-Wire		13
OC, CA & CS	50 & 60	480 Volt, 2-Wire		23
		600 Volt, 2-Wire		28

*Except for Type C, Sub E meters, rated from 100 to 300

16-G

WATTHOUR METERS

AND REGISTER RATIO DATA

TABLE 16-H POLYPHASE METERS

Type	Frequency (Cycles)	Rating	Remarks	See Table 16-H Column No.
Round	25–140	100 Volt, Polyphase		7
		200 Volt, Polyphase		14
		400 Volt, Polyphase		24
A	25–140	100 Volt, Polyphase		7
		200 Volt, Polyphase		14
		400 Volt, Polyphase		24
C Plain	25–140	100 Volt, Polyphase		11
		200 Volt, Polyphase		20
		400 Volt, Polyphase		32
		500 Volt, Polyphase		35
		100 Volt Y, 3-Phase, 4-Wire		20
		200 Volt Y, 3-Phase, 4-Wire		32
		400 Volt Y, 3-Phase, 4-Wire		39
C Sub A, B, C, D & E*	25–140	100 Volt, Polyphase		9
		200 Volt, Polyphase		18
		400 Volt, Polyphase		31
		500 Volt, Polyphase		34
		100 Volt Y, 3-Phase, 4-Wire		18
		200 Volt Y, 3-Phase, 4-Wire		31
		400 Volt Y, 3-Phase, 4-Wire		38
C Sub E (100–300 Amp Self-Contained)	25–140	100 Volt, Polyphase		2
		200 Volt, Polyphase		10
		400 Volt, Polyphase		19
		500 Volt, Polyphase		25
OA	25–140	100 Volt, Polyphase		11
		200 Volt, Polyphase		20
		400 Volt, Polyphase		32
		500 Volt, Polyphase		35
		100 Volt Y, 3-Phase, 4-Wire		16
		200 Volt Y, 3-Phase, 4-Wire		29
		400 Volt Y, 3-Phase, 4-Wire		37
OB C-2, 5, 7 & 10 CA-2, 5, 7 & 10 CS-2, 5, 7 & 10 CB-2, 7 & 10 CB-2F, 7F & 10F CAH-2 & 7 QCA-2, 5 & 7	25, 50 & 60			
		120 Volt, 2-Element		13
		240 Volt, 2-Element		23
		480 Volt, 2-Element		33
		600 Volt, 2-Element		36
OB, C-8, CA-8 CS-8, CB-8, CB-8F OAH-8 & QCA-8	25, 50 & 60	120 Volt, 2-El. 3-Phase, 4-Wire	Below Serial No. 15,213,261	23
		240 Volt, 2-El., 3-Phase, 4-Wire	Above Serial No. 15,213,261	17
			Below Serial No. 15,213,261	33
			Above Serial No. 15,213,261	30
OB C-3, 4, 6 & 9 CA-3, 4, 6 & 9 CS-3, 4, 6 & 9 CB-3, 4, 6 & 9	25, 50 & 60			
		120 Volt, 3-Element		17
		240 Volt, 3-Element		30
CB-3F, 4F, 6F & 9F CB-32, CB-32F	25, 50 60	120 Volts, 4-Elements		23
		240 Volts, 4-Elements		33
CB-38, CB-38F	25, 50 60	120 Volt, 4-Element		30
		3-Phase, 4-Wire		

Amperes (self-contained) which are listed separately.

TABLE

CONSTANTS AND

FOR WESTINGHOUSE A-C WATTHOUR

Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	Gear Ratio (R_g)	COLUMN NO.																		
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
				AMPERE RATING																		
1/6	600	0.1	6000	5																		
1/3	4800	1	30000			5																
1/3	4796 3/5	1	29978 3/4				5															
1/3	480	0.1	3000					5														
1/3	3600	1	30000						5							2.5						
1/3	300	0.1	3000	10						5												
1/3	2400	1	30000								5											
1/2	2400	1	20000																	2.5		
2/3	3000	1	15000									5										
2/3	2400	1	15000			10	10							5								
2/3	240	0.1	1500					10							5							
2/3	1800	1	15000						10							5						
2/3	150	0.1	1500	20						10							5					
2/3	1200	1	15000								10							5				
1	1600	1	10000			15	15												5			
1	1200	1	10000						15											5		
1 1/3	1500	1	7500									10									5	
1 1/3	1200	1	7500			20	20							10								
1 1/3	120	0.1	750					20							10							
1 1/3	900	1	7500													10						
1 1/3	750	1	7500	40						20							10					
1 1/3	600	1	7500															10				
1 2/3	960	1	6000			25	25															
1 2/3	720	1	6000						25													
2	1000	1	5000									15										
2	800	1	5000			30	30							15					10			
2	600	1	5000													15				10		
2 2/3	750	1	3750									20									10	
2 2/3	600	1	3750			40	40	40						20	20							
2 2/3	450	1	3750																			
2 2/3	375	1	3750	80						40							20					
3	533 1/3	1	3333 1/3																15			
3	400	1	3333 1/3																	15		
3 1/3	600	1	3000																			
3 1/3	480	1	3000			50								25								
3 1/3	360	1	3000						50							25						
4	500	1	2500									30									15	
4	400	1	2500			60	60							30								
4	300	1	2500																			
5	320	1	2000			75													25			
5	240	1	2000						75											25		
5 1/3	375	1	1875									40									20	
5 1/3	300	1	1875			80	80	80						40	40							
5 1/3	225	1	1875																			
5 1/3	187 1/2	1	1875							80							40					
6	266 2/3	1	1666 2/3																			
6	200	1	1666 2/3																			
6 2/3	300	1	1500		100																	
6 2/3	240	1	1500			100	100							50								
6 2/3	180	1	1500													50						
8	250	1	1250									60									30	
8	2500	10	12500		120																	
8	200	1	1250			120	120							60								
8	150	1	1250																			
8 1/3	192	1	1200																			
8 1/3	144	1	1200																			
10	200	1	1000																			
10	2000	10	10000		150																	
10	160	1	1000			150	150							75					50			
10	120	1	1000													75				50		
10 2/3	187 1/2	1	937 1/2									80									40	
10 2/3	150	1	937 1/2											80	80							
10 2/3	93 3/4	1	937 1/2														80					
12	1333 1/3	10	8333 1/3																			
13 1/3	150	1	750									100										

16-H

REGISTER RATIO DATA

METERS LISTED IN TABLE 16-G

COLUMN NO.																				Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	Gear Ratio (R_g)
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39				
AMPERE RATING																							
																				1/6	600	0.1	6000
																				1/3	4800	1	30000
																				1/3	4796 3/5	1	29978 3/4
																				1/3	480	0.1	3000
																				1/3	3600	1	30000
																				1/3	360	0.1	3000
																				1/3	2400	1	30000
																				1/2	2400	1	20000
																				2/3	3000	1	15000
																				2/3	2400	1	15000
																				2/3	240	0.1	1500
			2.5																	2/3	1800	1	15000
																				2/3	150	0.1	1500
																				2/3	1200	1	15000
																				1	1600	1	10000
										2.5										1	1200	1	10000
																				1 1/3	1500	1	7500
5	5																			1 1/3	1200	1	7500
		5																		1 1/3	120	0.1	750
			5										2.5							1 1/3	900	1	7500
				5																1 1/3	750	1	7500
																				1 1/3	600	1	7500
						5	5													1 2/3	960	1	6000
								5								2.5				1 2/3	720	1	6000
																				2	1000	1	5000
									5											2	800	1	5000
										5										2	600	1	5000
											5									2 2:3	750	1	3750
10	10	10										5								2 2/3	600	1	3750
			10										5							2 2/3	450	1	3750
				10																2 2/3	375	1	3750
																				3	533 1/3	1	3333 1/3
																				3	400	1	3333 1/3
														5						3 1/3	600	1	3000
						10	10								5					3 1/3	480	1	3000
								10								5				3 1/3	360	1	3000
																				4	500	1	2500
15	15								10								5			4	400	1	2500
			15							10										4	300	1	2500
						15	15													5	320	1	2000
								15												5	240	1	2000
											10							5		5 1/3	375	1	1875
20	20	20										10							5	5 1/3	300	1	1875
													10							5 1/3	225	1	1875
				20																5 1/3	187 1/2	1	1875
									15											6	266 2/3	1	1666 2/3
										15										6	200	1	1666 2/3
														10						6 2/3	300	1	1500
25	25					20	20								10					6 2/3	240	1	1500
			25													10				6 2/3	180	1	1300
											15									8	250	1	1250
																				8	2500	10	12500
30												15					10			8	200	1	1250
													15							8	150	1	1250
						25	25													8 1/3	192	1	1200
								25												8 1/3	144	1	1200
														15						10	300	1	1000
																				10	2000	10	10000
						30			25						15					10	100	1	1000
										25						15				10	120	1	1000
											30							10		10 2/3	187 1/2	1	937 1/2
40	40	40										30							10	10 2/3	150	1	937 1/2
				40																10 2/3	93 3/4	1	937 1/2
																	15			12	1333 1/3	10	8333 1/3
														20						13 1/3	150	1	750

TABLE 16-H (Continued)—WESTINGHOUSE

Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	Gear Ratio (R_g)	COLUMN NO.																		
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
				AMPERE RATING																		
13 1/3	1500	10	7500		200								100									
13 1/3	120	1	750			200	200							100								
13 1/3	1200	10	7500																			
13 1/3	900	10	7500																			
15	1066 2/3	10	6666 2/3																75			
15	800	10	6666 2/3																	75		
16	1250	10	6250									120	120								60	
16	1000	10	6250											120								
16	1000	10	6250																			
16 2/3	960	10	6000																			
16 2/3	720	10	6000																			
20	1000	10	5000		300							150	150									
20	800	10	5000			300	300							150								
20	800	10	5000																			
20	600	10	5000																			
21 1/3	937 1/2	10	4687 1/2																		80	
21 1/3	750	10	4687 1/2																			
21 1/3	750	10	4687 1/2																			
21 1/3	75	1	468 3/4																			
21 1/3	468 3/4	10	4687 1/2																			
25	640	10	4000																			
25	480	10	4000																			
26 2/3	750	10	3750									200	200								100	100
26 2/3	600	10	3750											200								
26 2/3	600	10	3750																			
26 2/3	450	10	3750																			
30	533 1/3	10	3333 1/3																			
30	400	10	3333 1/3																			
32	625	10	3125																		120	120
32	500	10	3125																			
33 1/3	600	10	3000																			
33 1/3	480	10	3000																			
33 1/3	480	10	3000																			
33 1/3	360	10	3000																			
40	500	10	2500									300	300								150	150
40	400	10	2500											300								
40	400	10	2500																			
40	300	10	2500																			
42 2/3	468 3/4	10	2343 3/4																			
42 2/3	375	10	2343 3/4																			
50	400	10	2000																			
50	320	10	2000																			
50	320	10	2000																			
50	240	10	2000																			
53 1/3	375	10	1875																		200	200
53 1/3	300	10	1875																			
60	266 2/3	10	1666 2/3																			
64	312 1/2	10	1562 1/2																			
64	250	10	1562 1/2																			
66 2/3	300	10	1500																			
66 2/3	240	10	1500																			
80	250	10	1250																		300	
80	2500	100	12500																			300
80	200	10	1250																			
100	200	10	1000																			
100	160	10	1000																			
106 2/3	187 1/2	10	937 1/2																			
106 2/3	150	10	937 1/2																			
133 1/3	150	10	750																			
133 1/3	120	10	750																			
160	1250	100	6250																			
160	1000	100	6250																			
200	1000	100	5000																			
200	800	100	5000																			

NOTES.—This table may include ampere sizes which were not produced in certain types of meters due to the fact that all meter types in each group or column were not always made in the same current ratings. However, all ampere ratings of all meters in the group have been listed.

Constants and Register Ratio Data

COLUMN NO.																				Watthour Constant (K_h)	Register Ratio (R_r)	Register Constant (K_r)	Gear Ratio (R_g)
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39				
AMPERE RATING																							
																				13 1/3	1500	10	7500
	50					40	40								20					13 1/3	120	1	750
50												25								13 1/3	1200	10	7500
			50										25							13 1/3	900	10	7500
																				15	1066 2/3	10	6666 2/3
																				15	800	10	6666 2/3
											30							15		16	1250	10	6250
60												30							15	16	1000	10	6250
	60																			16	1000	10	6250
							50								25					16 2/3	960	10	6000
								50								25				16 2/3	720	10	6000
														30						20	1000	10	5000
75						60									30					20	800	10	5000
	75						60		50								25			20	800	10	5000
			75							50										20	600	10	5000
											40							20		21 1/3	937 1/2	10	4687 1/2
80												40							20	21 1/3	750	10	4687 1/2
	80																			21 1/3	750	10	4687 1/2
		80																		21 1/3	75	1	468 3/4
				80																21 1/3	468 3/4	10	4687 1/2
							75													25	640	10	4000
								75												25	480	10	4000
														40						26 2/3	750	10	3750
100						80									40					26 2/3	600	10	3750
							80					50								26 2/3	600	10	3750
													50							26 2/3	450	10	3750
									75											30	533 1/3	10	3333 1/3
										75										30	400	10	3333 1/3
											60							30		32	625	10	3125
120												60							30	32	500	10	3125
					100															33 1/3	600	10	3000
						100														33 1/3	480	10	3000
															50					33 1/3	480	10	3000
																50				33 1/3	360	10	3000
					120									60						40	500	10	2500
150						120									60					40	400	10	2500
												75					50			40	400	10	2500
													75							40	300	10	2500
											80							40		42 2/3	468 3/4	10	2343 3/4
												80							40	42 2/3	375	10	2343 3/4
					150															50	400	10	2000
						150														50	320	10	2000
															75					50	320	10	2000
																75				50	240	10	2000
											100			80						53 1/3	375	10	1875
200												100			80					53 1/3	300	10	1875
																	75			60	266 2/3	10	1666 2/3
											120									64	312 1/2	10	1562 1/2
												120								64	250	10	1562 1/2
					200									100						66 2/3	300	10	1500
						200									100					66 2/3	240	10	1500
											150			120						80	250	10	1250
																				80	2500	100	12500
300												150			120					80	200	10	1250
					300									150						100	200	10	1000
						300									150					100	160	10	1000
											200									106 2/3	187 1/2	10	937 1/2
												200								106 2/3	150	10	937 1/2
														200						133 1/3	150	10	750
															200					133 1/3	120	10	750
											300									160	1250	100	6250
												300								160	1000	100	6250
														300						200	1000	100	5000
															300					200	800	100	5000

See Section No. 10 for Standard Dial Constants issued August, 1938, to meter manufacturers.

TABLE 16-I

WESTINGHOUSE A-C WATTHOUR METERS

INDEX FOR TABLE 16-L

Meter Type and Description	See Table 16-L Key Line
Round Type, single-phase and polyphase	I
Type A, single and polyphase	I
Type B, Serial Nos. below 418,000 (approx.)	D
Type B, Serial Nos. above 418,000 (approx.)	B
Type B, prepayment	B
Type C, single-phase and plain polyphase, house type	B
Type C, polyphase, house type (Sub A to Sub E except Sub E, 100 to 300 amperes)	F
Type C, polyphase, house type (Sub E, 100 to 300 amperes only)	E
Type C, single-phase and polyphase, switchboard type (plain and Sub A, below Serial No. 838,688)	G
Type C, single-phase, switchboard type (Sub A to Sub D, Serial Nos. above 838,688)	D
Type C, polyphase, switchboard type (Sub A to Sub D, Serial Nos. above 838,688)	H
Type OA, single-phase, plain (Serial Nos. below 886,500—approx.)	C
Type OA, single-phase (Sub A to Sub F, Serial Nos. above 886,500—approx.) and polyphase	B
Type OB, single-phase and polyphase	A
Types OC, C-2, 3, 4, 5, 6, 7, 8, 9, & 10—singlephase and polyphase	A
Types CA, CA-2, 3, 4, 5, 6, 7, 8, 9, & 10—single-phase and polyphase	A
Types CS, CSH, CS-2, 3, 4, 5, 6, 7, 8, 9, & 10—singlephase and polyphase	A
Types CB, CB-2, 3, 4, 6, 7, 8, 9, 10, 32 & 38—singlephase and polyphase	A
Types CB-F, CB-2F, 3F, 4F, 6F, 7F, 8F, 9F, 10F, 32F & 38F—singlephase and polyphase	A
Types CAH, CAH-2, 7 & 8—singlephase and polyphase	A
Types QCA, QCA-2, 5, 7 & 8—singlephase and polyphase	A
Types XCA & XCS—singlephase	A

TABLE 16-J

FORMULAS FOR WESTINGHOUSE METERS

(FOR USE WITH TABLES 16-I, 16-K AND 16-L)

Formula Reference	Formula
(a)	For all meters except the types C-8, CA-8 and CS-8, and all other 2-element meters for 3-phase, 4-wire wye supply: $\text{Kw} = \frac{V \times I \times N \times R_c \times R_p}{1000}$
(b)	For CA-8 and CS-8 meters below Serial No. 15, 213, 261 and for C-8 and all other 2-element meters for 3-phase, 4-wire wye supply: $\text{Kw} = \frac{2 \times V \times I \times N \times R_c \times R_p}{1000}$
(c)	For CA-8, CS-8 and all other 2- or 4-element meters for 3-phase, 4-wire wye supply above Serial No. 15,213,261: $\text{Kw} = \frac{1.5 \times V \times I \times N \times R_c \times R_p}{1000}$

Where Kw = the nominal kilowatt rating of the meter, defined as the load which will cause the disk to rotate 1500 revolutions per hour (except for all Round type, all type A, and for Type C polyphase, house type, Sub E, 100- to 300-ampere meters which rotate at 3,000 revolutions per hour.)

V = the voltage rating of one element (100 volts for 115–120 volt meters, 200 volts for 230–240 volt meters, etc.)

I = the current rating of one element

N = the number of elements

R_c = the current transformer ratio

R_p = the potential transformer ratio

TABLE 16-K

DETERMINATION OF WESTINGHOUSE REGISTER DATA IN TABLE 16-L

(INITIAL REFERENCE TABLES 16-I AND 16-J)

For Kw Ratings between	Use Value of Kw given below	And multiply the values of K_h and K_r by
0 and 16	Same	Use directly
16 " 160	1/10	10
160 " 1,600	1/100	100
1,600 " 16,000	1/1,000	1,000
16,000 " 160,000	1/10,000	10,000

NOTE: On some of the older meters, where registers required multipliers of 10, or multiples thereof, a nominal register multiplier of $K_r = 1$ was always used, but the necessary multiplier figure for each dial to give direct reading was marked within the dial circle, viz., "10's," "100's," etc. The above table, however, is so constructed that one revolution of the first pointer equals K_r times 10 kwhr regardless of whether the first dial is marked "10's," "100's," etc.

Example: A 5-ampere, 115-volt, C-2 meter with a current transformer ratio of 200/5 and a potential transformer ratio of 2300/115, has a rating of 800 kw, *i.e.*:

$$\frac{100 \times 5 \times 2 \times 40 \times 20}{1000} = 800 \text{ kw}$$

800 kw lies between 160 and 1600 (3rd line at left). Using 1/100 of the kw value or 8, we find in Table No. 16-L, under "Nominal Rating—Kw," the value of 8 and opposite it, in the Key Line A (for C-2 meters), the values of K_h and K_r equal to 5⅓ and 1, respectively, each of which must be multiplied by 100 (according to the adjoining table). The constants for the above meter, then, are as follows:

$$K_h = 533\tfrac{1}{3},\ K_r = 100,\ R_r = 225 \text{ and } R_g = 1875$$

TABLE 16-L

CONSTANTS AND REGISTER DATA

FOR WESTINGHOUSE A-C WATTHOUR METERS

Nominal Rating Kw	Key Line	Watthour Constant (K_h)	Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
0.5	A	1/3	1	3600	30000
0.5	B	1/3	1	4800*	30000*
0.5	C	1/3	1	2400	30000
0.5	D	1/3	1/10	480	3000
0.5	I	1/6	1/10	600	6000
0.75	A	1/2	1	2400	20000
0.8	D	8/15	1/10	300	1875
0.8	I	4/15	1/10	375	3750
1.0	A	2/3	1	1800	15000
1.0	B	2/3	1	2400	15000
1.0	C	2/3	1	1200	15000
1.0	D	2/3	1/10	240	1500
1.0	F	2/3	1	3000	15000
1.0	G	2/3	1/10	480	1500
1.0	H	2/3	1/10	300	1500
1.0	I	1/3	1/10	300	3000
1.2	D	4/5	1/10	200	1250
1.2	G	4/5	1/10	400	1250
1.2	H	4/5	1/10	250	1250
1.25	A	5/6	1	1440	12000
1.25	D	5/6	1/10	192	1200
1.25	G	5/6	1/10	384	1200
1.25	H	5/6	1/10	240	1200
1.44	D	24/25	1/10	166 2/3	1041 2/3
1.44	G	24/25	1/10	333 1/3	1041 2/3
1.44	H	24/25	1/10	208 1/3	1041 2/3
1.5	A	1	1	1200	10000
1.5	B	1	1	1600	10000
1.5	D	1	1/10	160	1000
1.5	G	1	1/10	320	1000
1.5	H	1	1/10	200	1000
1.6	D	1 1/15	1/10	150	937 1/2
1.6	G	1 1/15	1/10	300	937 1/2
1.6	H	1 1/15	1/10	187 1/2	937 1/2
1.6	I	8/15	1/10	187 1/2	1875
1.75	A	1 1/6	1	1028 4/7	8571 3/7
1.8	A	1 1/5	1	1000	8333 1/3
1.8	D	1 1/5	1/10	133 1/3	833 1/3
1.8	G	1 1/5	1/10	266 2/3	833 1/3
1.8	H	1 1/5	1/10	166 2/3	833 1/3
1.875	A	1 1/4	1	960	8000
2.0	A	1 1/3	1	900	7500
2.0	B	1 1/3	1	1200	7500
2.0	C	1 1/3	1	600	7500
2.0	D	1 1/3	1/10	120	750
2.0	E	2/3	1/10	300	1500
2.0	F	1 1/3	1	1500	7500
2.0	G	1 1/3	1/10	240	750
2.0	H	1 1/3	1/10	150	750
2.0	I	2/3	1/10	150	1500
2.1	A	1 2/5	1	857 1/7	7142 6/7
2.2	A	1 7/15	1	818 2/11	6818 2/11
2.25	A	1 1/2	1	800	6666 2/3
2.4	A	1 3/5	1	750	6250
2.4	B	1 3/5	1	1000	6250
2.4	D	1 3/5	1/10	100	625
2.4	E	4/5	1	2500	12500
2.4	F	1 3/5	1	1250	6250
2.4	G	1 3/5	1/10	200	625
2.4	H	1 3/5	1/10	125	625
2.5	A	1 2/3	1	720	6000
2.5	B	1 2/3	1	960	6000
2.5	D	1 2/3	1/10	96	600
2.5	G	1 2/3	1/10	192	600
2.5	H	1 2/3	1/10	120	600
2.7	A	1 4/5	1	666 2/3	5555 2/9
2.8	A	1 13/15	1	642 6/7	5357 1/7
3.0	A	2	1	600	5000
3.0	B	2	1	800	5000
3.0	D	2	1/10	80	500
3.0	E	1	1	2000	10000
3.0	F	2	1	1000	5000
3.0	G	2	1/10	160	500
3.0	H	2	1/10	100	500
3.15	A	2 1/10	1	571 3/7	4761 19/21
3.2	A	2 2/15	1	562 1/2	4687 1/2
3.2	B	2 2/15	1	750	4687 1/2
3.2	D	2 2/15	1/10	75	468 3/4
3.2	F	2 2/15	1	937 1/2	4687 1/2
3.2	G	2 2/15	1/10	150	468 3/4
3.2	H	2 2/15	1/10	93 3/4	468 3/4
3.2	I	1 1/15	1/10	93 3/4	937 1/2
3.5	A	2 1/3	1	514 2/7	4285 5/7
3.6	A	2 2/5	1	500	4166 2/3
3.6	D	2 2/5	1/10	66 2/3	416 2/3
3.6	G	2 2/5	1/10	133 1/3	416 2/3
3.6	H	2 2/5	1/10	83 1/3	416 2/3
3.75	A	2 1/2	1	480	4000
3.75	B	2 1/2	1	640	4000
4.0	A	2 2/3	1	450	3750
4.0	B	2 2/3	1	600	3750
4.0	D	2 2/3	1	600	3750
4.0	E	1 1/3	1	1500	7500
4.0	F	2 2/3	1	750	3750
4.0	G	2 2/3	1	1200	3750
4.0	H	2 2/3	1	750	3750
4.0	I	1 1/3	1	750	7500
4.2	A	2 4/5	1	428 4/7	3571 3/7
4.4	A	2 14/15	1	409 1/11	3409 1/11
4.5	A	3	1	400	3333 1/3

* For Type B, above Serial No. 418,000 and Type C, below Serial No. 158,000 } $R_r = 4796.6$ and $R_g = 29978.8$

TABLE 16-L (Continued)—WESTINGHOUSE Constants and Register Data

Nominal Rating Kw	Key Line	Watt-hour Constant (K_h)	Register Constant (K_r)	Register Ratio (R_r)	Gear Ratio (R_g)
4.8	A	3 1/5	1	375	3125
4.8	B	3 1/5	1	500	3125
4.8	D	3 1/5	1	500	3125
4.8	E	1 3/5	1	1250	6250
4.8	F	3 1/5	1	625	3125
4.8	G	3 1/5	1	1000	3125
4.8	H	3 1/5	1	625	3125
5.0	A	3 1/3	1	360	3000
5.0	B	3 1/3	1	480	3000
5.0	C	3 1/3	10	2400	30000
5.0	D	3 1/3	1	480	3000
5.0	G	3 1/3	1	960	3000
5.0	H	3 1/3	1	600	3000
5.0	I	1 2/3	1	600	6000
5.25	A	3 1/2	1	342 6/7	2857 1/7
5.4	A	3 3/5	1	333 1/3	2777 7/9
5.6	A	3 11/15	1	321 3/7	2678 4/7
5.625	A	3 3/4	1	320	2666 2/3
6.0	A	4	1	300	2500
6.0	B	4	1	400	2500
6.0	D	4	1	400	2500
6.0	E	2	1	1000	5000
6.0	F	4	1	500	2500
6.0	G	4	1	800	2500
6.0	H	4	1	500	2500
6.25	A	4 1/6	1	288	2400
6.3	A	4 1/5	1	285 5/7	2380 20/21
6.4	A	4 4/15	1	281 1/4	2343 3/4
6.4	D	4 4/15	1	375	2343 3/4
6.4	F	4 4/15	1	468 3/4	2343 3/4
6.4	G	4 4/15	1	750	2343 3/4
6.4	H	4 4/15	1	468 3/4	2343 3/4
6.4	I	2 2/15	1	468 3/4	4687 1/2
6.75	A	4 1/2	1	266 2/3	2222 2/9
7.0	A	4 2/3	1	257 1/7	2142 6/7
7.2	A	4 4/5	1	250	2083 1/3
7.2	D	4 4/5	1	333 1/3	2083 1/3
7.2	G	4 4/5	1	666 2/3	2083 1/3
7.2	H	4 4/5	1	416 2/3	2083 1/3
7.5	A	5	1	240	2000
7.5	B	5	1	320	2000
7.5	D	5	1	320	2000
7.5	G	5	1	640	2000
7.5	H	5	1	240	2000
8.0	A	5 1/3	1	225	1875
8.0	B	5 1/3	1	300	1875
8.0	D	5 1/3	1	300	1875
8.0	E	2 2/3	1	750	3750
8.0	F	5 1/3	1	375	1875
8.0	G	5 1/3	1	600	1875
8.0	H	5 1/3	1	375	1875
8.0	I	2 2/3	1	375	3750
8.4	A	5 3/5	1	214 2/7	1785 5/7
8.8	A	5 13/15	1	204 6/11	1704 6/11
9.0	A	6	1	200	1666 2/3
9.6	A	6 2/5	1	187 1/2	1562 1/2
9.6	D	6 2/5	1	250	1562 1/2
9.6	E	3 1/5	1	625	3125
9.6	G	6 2/5	1	500	1562 1/2
9.6	H	6 2/5	1	312 1/2	1562 1/2
10.0	A	6 2/3	1	180	1500
10.0	B	6 2/3	1	240	1500
10.0	D	6 2/3	1	240	1500
10.0	E	3 1/3	1	600	3000
10.0	F	6 2/3	10	3000	15000
10.0	G	6 2/3	1	480	1500
10.0	H	6 2/3	1	300	1500
10.0	I	3 1/3	1	300	3000
10.5	A	7	1	171 3/7	1428 4/7
11.0	A	7 1/3	1	163 7/11	1363 7/11
11.2	A	7 7/15	1	160 5/7	1339 2/7
11.25	A	7 1/2	1	160	1333 1/3
12.0	A	8	1	150	1250
12.0	B	8	1	200	1250
12.0	D	8	1	200	1250
12.0	E	4	1	500	2500
12.0	F	8	1	250	1250
12.0	G	8	1	400	1250
12.0	H	8	1	250	1250
12.5	A	8 1/3	1	144	1200
12.5	B	8 1/3	1	192	1200
12.5	D	8 1/3	1	192	1200
12.5	G	8 1/3	1	384	1200
12.5	H	8 1/3	1	240	1200
13.5	A	9	1	133 1/3	1111 1/9
14.0	A	9 1/3	1	128 4/7	1071 6/7
14.4	A	9 3/5	1	125	1041 2/3
14.4	D	9 3/5	1	166 2/3	1041 2/3
14.4	G	9 3/5	1	333 1/3	1041 2/3
14.4	H	9 3/5	1	208 1/3	1041 2/3
15.0	A	10	1	120	1000
15.0	B	10	10	1600	10000
15.0	D	10	1	160	1000
15.0	E	5	1	400	2000
15.0	G	10	1	320	1000
15.0	H	10	1	200	1000
15.75	A	10 1/2	1	114 2/7	952 8/21
16.0	A	10 2/3	1	112 1/2	937 1/2
16.0	D	10 2/3	1	150	937 1/2
16.0	E	5 1/3	1	375	1875
16.0	G	10 2/3	1	300	937 1/2
16.0	H	10 2/3	1	187 1/2	937 1/2
16.0	I	5 1/3	1	187 1/2	1875

See Section 17 for Standard Register Constants.

TABLE 16-M

CONSTANTS FOR WESTINGHOUSE TYPE C METAL AND GLASS COVER WATTHOUR METERS

Previous to Sub A, Serial No. 838,688

Single-phase and polyphase **Switchboard Pattern** **25- to 140-cycle**

Rating in Kw	Numerical Value of 1 Revolution of 1st Dial Pointer	Watthour Constant (K_h)	Register Ratio (R_r)	Rating in Kw	Numerical Value of 1 Revolution of 1st Dial Pointer	Watthour Constant (K_h)	Register Ratio (R_r)
1	1	$^{2}/_{3}$	480	80	100	$53^{1}/_{3}$	600
2	1	$1^{1}/_{3}$	240	96	100	64	500
$2^{1}/_{2}$	1	$1^{2}/_{3}$	192	100	100	$66^{2}/_{3}$	480
3	1	2	160	120	100	80	400
4	10	$2^{2}/_{3}$	1200	125	100	$83^{1}/_{3}$	384
5	10	$3^{1}/_{3}$	960	150	100	100	320
6	10	4	800	160	100	$106^{2}/_{3}$	300
$7^{1}/_{2}$	10	5	640	180	100	120	$266^{2}/_{3}$
8	10	$5^{1}/_{3}$	600	200	100	$133^{1}/_{3}$	240
10	10	$6^{2}/_{3}$	480	240	100	160	200
12	10	8	400	250	100	$166^{2}/_{3}$	192
$12^{1}/_{2}$	10	$8^{1}/_{3}$	384	300	100	200	160
15	10	10	320	320	100	$213^{1}/_{3}$	150
16	10	$10^{2}/_{3}$	300	360	100	240	$133^{1}/_{3}$
18	10	12	$266^{2}/_{3}$	400	1000	$266^{2}/_{3}$	1200
20	10	$13^{1}/_{3}$	240	480	1000	320	1000
24	10	16	200	500	1000	$333^{1}/_{3}$	960
25	10	$16^{2}/_{3}$	192	600	1000	400	800
30	10	20	160	640	1000	$426^{2}/_{3}$	750
32	10	$21^{1}/_{3}$	150	720	1000	480	$666^{2}/_{3}$
36	10	24	$133^{1}/_{3}$	750	1000	500	640
40	100	$26^{2}/_{3}$	1200	800	1000	$533^{1}/_{3}$	600
48	100	32	1000	960	1000	640	500
50	100	$33^{1}/_{3}$	960	1000	1000	$666^{2}/_{3}$	480
60	100	40	800	1200	1000	800	400
64	100	$42^{2}/_{3}$	750	1250	1000	$833^{1}/_{3}$	384
72	100	48	$666^{2}/_{3}$	1440	1000	960	$333^{1}/_{3}$
75	100	50	640	1500	1000	1000	320

Larger ratings proportional.

NOTE.—$R_g = R_r \times 3.125$, in which R_g = gear ratio
$K_t = 3600 \times K_h$, in which K_t = test constant

Numerical value of register constant = 1

TABLE 16-N

CONSTANTS FOR WESTINGHOUSE TYPE C METAL AND GLASS COVER WATTHOUR METERS

FOR METERS BETWEEN TYPE C, SUB A, SERIAL NO. 838,688 AND THROUGH TYPE C, SUB B

Single-phase **Switchboard Pattern** **25- to 140-cycle**

Rating in Kw	Numerical Value of 1 Revolution of 1st Dial Pointer	Watthour Constant (K_h)	Register Ratio (R_r)	Rating in Kw	Numerical Value of 1 Revolution of 1st Dial Pointer	Watthour Constant (K_h)	Register Ratio (R_r)
1	1	2/3	240	80	100	53 1/3	300
2	1	1 1/3	120	96	100	64	250
2 1/2	1	1 2/3	96	100	100	66 2/3	240
3	1	2	80	120	100	80	200
4	10	2 2/3	600	125	100	83 1/3	192
5	10	3 1/3	480	150	100	100	160
6	10	4	400	160	100	106 2/3	150
7 1/2	10	5	320	180	100	120	133 1/3
8	10	5 1/3	300	200	100	133 1/3	120
10	10	6 2/3	240	240	100	160	100
12	10	8	200	250	100	166 2/3	96
12 1/2	10	8 1/3	192	300	100	200	80
15	10	10	160	320	100	213 1/3	75
16	10	10 2/3	150	360	100	240	66 2/3
18	10	12	133 1/3	400	1000	266 2/3	600
20	10	13 1/3	120	480	1000	320	500
24	10	16	100	500	1000	333 1/3	480
25	10	16 2/3	96	600	1000	400	400
30	10	20	80	640	1000	426 2/3	375
32	10	21 1/3	75	720	1000	480	333 1/3
36	10	24	66 2/3	750	1000	500	320
40	100	26 2/3	600	800	1000	533 1/3	300
48	100	32	500	960	1000	640	250
50	100	33 1/3	480	1000	1000	666 2/3	240
60	100	40	400	1200	1000	800	200
64	100	42 2/3	375	1250	1000	833 1/3	192
72	100	48	333 1/3	1440	1000	960	166 2/3
75	100	50	320	1500	1000	1000	160

Larger ratings proportional.

NOTE.—R_g = $R_r \times 6.25$, in which R_g = gear ratio.
$K_t = 3600 \times K_h$, in which K_t = test constant

Numerical value of register constant = 1

TABLE 16-O

CONSTANTS FOR WESTINGHOUSE TYPE C METAL AND GLASS COVER WATTHOUR METERS

FOR METERS BETWEEN TYPE C, SUB A, SERIAL NO. 838,688 AND THROUGH TYPE C, SUB B

Polyphase **Switchboard Pattern** **25- to 140-cycle**

Rating in Kw	Numerical Value of 1 Revolution of 1st Dial Pointer	Watthour Constant (K_h)	Register Ratio (R_r)	Rating in Kw	Numerical Value of 1 Revolution of 1st Dial Pointer	Watthour Constant (K_h)	Register Ratio (R_r)
1	1	$\frac{2}{3}$	300	80	100	$53\frac{1}{3}$	375
2	1	$1\frac{1}{3}$	150	96	100	64	312
$2\frac{1}{2}$	1	$1\frac{2}{3}$	120	100	100	$66\frac{2}{3}$	300
3	1	2	100	120	100	80	250
4	10	$2\frac{2}{3}$	750	125	100	$83\frac{1}{3}$	240
5	10	$3\frac{1}{3}$	600	150	100	100	200
6	10	4	500	160	100	$106\frac{2}{3}$	$187\frac{1}{2}$
$7\frac{1}{2}$	10	5	400	180	100	120	$166\frac{2}{3}$
8	10	$5\frac{1}{3}$	375	200	100	$133\frac{1}{3}$	150
10	10	$6\frac{2}{3}$	300	240	100	160	125
12	10	8	250	250	100	$166\frac{2}{3}$	120
$12\frac{1}{2}$	10	$8\frac{1}{3}$	240	300	100	200	100
15	10	10	200	320	100	$213\frac{1}{3}$	$93\frac{3}{4}$
16	10	$10\frac{2}{3}$	$187\frac{1}{2}$	360	100	240	$83\frac{1}{3}$
18	10	12	$166\frac{2}{3}$	400	1000	$266\frac{2}{3}$	750
20	10	$13\frac{1}{3}$	150	480	1000	320	625
24	10	16	125	500	1000	$333\frac{1}{3}$	600
25	10	$16\frac{2}{3}$	120	600	1000	400	500
30	10	20	100	640	1000	$426\frac{2}{3}$	$468\frac{3}{4}$
32	10	$21\frac{1}{3}$	$93\frac{3}{4}$	720	1000	480	$416\frac{2}{3}$
36	10	24	$83\frac{1}{3}$	750	1000	500	400
40	100	$26\frac{2}{3}$	750	800	1000	$533\frac{1}{3}$	375
48	100	32	625	960	1000	640	$312\frac{1}{2}$
50	100	$33\frac{1}{3}$	600	1000	1000	$666\frac{2}{3}$	300
60	100	40	500	1200	1000	800	250
64	100	$42\frac{2}{3}$	$468\frac{3}{4}$	1250	1000	$833\frac{1}{3}$	240
72	100	48	$416\frac{2}{3}$	1440	1000	960	$208\frac{1}{3}$
75	100	50	400	1500	1000	1000	200

Larger ratings proportional.

NOTE.—$R_g = R_r \times 5$, in which R_g = gear ratio
$K_t = 3600 \times K_h$, in which K_t = test constant

Numerical value of register constant = 1

TABLE 16-P

CONSTANTS FOR WESTINGHOUSE TYPE C SUB C AND SUB D METAL AND GLASS COVER WATTHOUR METERS

Single-phase, 25- to 140-cycle **Switchboard Pattern**

Rating in Kw	Watthour Constant (K_h)	Register Constant (K_r)	Register Ratio (R_r)	Rating in Kw	Watthour Constant (K_h)	Register Constant (K_r)	Register Ratio (R_r)
1	$^2/_3$	0.1	240	80	$53^1/_3$	10	300
2	$1^1/_3$	0.1	120	96	64	10	250
$2^1/_2$	$1^2/_3$	0.1	96	100	$66^2/_3$	10	240
3	2	0.1	80	120	80	10	200
4	$2^2/_3$	1	600	125	$83^1/_3$	10	192
5	$3^1/_3$	1	480	150	100	10	160
6	4	1	400	160	$106^2/_3$	10	150
$7^1/_2$	5	1	320	180	120	10	$133^1/_3$
8	$5^1/_3$	1	300	200	$133^1/_3$	10	120
10	$6^2/_3$	1	240	240	160	10	100
12	8	1	200	250	$166^2/_3$	10	96
$12^1/_2$	$8^1/_3$	1	192	300	200	10	80
15	10	1	160	320	$213^1/_3$	10	75
16	$10^2/_3$	1	150	360	240	10	$66^2/_3$
18	12	1	$133^1/_3$	400	$266^2/_3$	100	600
20	$13^1/_3$	1	120	480	320	100	500
24	15	1	100	500	$333^1/_3$	100	480
25	$16^2/_3$	1	96	600	400	100	400
30	20	1	80	640	$426^2/_3$	100	375
32	$21^1/_3$	1	75	720	480	100	$333^1/_3$
36	24	1	$66^2/_3$	750	500	100	320
40	$26^2/_3$	10	600	800	$533^1/_3$	100	300
48	32	10	500	960	640	100	250
50	$33^1/_3$	10	480	1000	$666^2/_3$	100	240
60	40	10	400	1200	800	100	200
64	$42^2/_3$	10	375	1250	$833^1/_3$	100	192
72	48	10	$333^1/_3$	1440	960	100	$166^2/_3$
75	50	10	320	1500	1000	100	160

Larger ratings proportional.

NOTE.—$R_g = R_r \times 6.25$, in which R_g = gear ratio
$K_t = 3600 \times K_h$, in which K_t = test constant

Numerical value of one revolution of first dial pointer = $K_r \times 10$

TABLE 16-Q

CONSTANTS FOR WESTINGHOUSE TYPE C SUB C AND SUB D METAL AND GLASS COVER WATTHOUR METERS

Polyphase, 25- to 140-cycle **Switchboard Pattern**

Rating in Kw	Watthour Constant (K_h)	Register Constant (K_r)	Register Ratio (R_r)	Rating in Kw	Watthour Constant (K_h)	Register Constant (K_r)	Register Ratio (R_r)
1	2/3	0.1	300	80	53 1/3	10	375
2	1 1/3	0.1	150	96	64	10	312
2 1/2	1 2/3	0.1	120	100	66 2/3	10	300
3	2	0.1	100	120	80	10	250
4	2 2/3	1	750	125	83 1/3	10	240
5	3 1/3	1	600	150	100	10	200
6	4	1	500	160	106 2/3	10	187 1/2
7 1/2	5	1	400	180	120	10	166 2/3
8	5 1/3	1	375	200	133 1/3	10	150
10	6 2/3	1	300	240	160	10	125
12	8	1	250	250	166 2/3	10	120
12 1/2	8 1/3	1	240	300	200	10	100
15	10	1	200	320	213 1/3	10	93 3/4
16	10 2/3	1	187 1/2	360	240	10	83 1/3
18	12	1	166 2/3	400	266 2/3	100	750
20	13 1/3	1	150	480	320	100	625
24	15	1	125	500	333 1/3	100	600
25	16 2/3	1	120	600	400	100	500
30	20	1	100	640	426 2/3	100	468 3/4
32	21 1/3	1	93 3/4	720	480	100	416 2/3
36	24	1	83 1/3	750	500	100	400
40	26 2/3	10	750	800	533 1/3	100	375
48	32	10	625	960	640	100	312 1/2
50	33 1/3	10	600	1000	666 2/3	100	300
60	40	10	500	1200	800	100	250
64	42 2/3	10	468 3/4	1250	833 1/3	100	240
72	48	10	416 2/3	1440	960	100	208 1/3
75	50	10	400	1500	1000	100	200

Larger ratings proportional.

NOTE.—$R_g = R_r \times 5$, in which R_g = gear ratio

$K_t = 3600 \times K_h$, in which K_t = test constant

Numerical value of one revolution of first dial pointer = $K_r \times 10$

TABLE 16-R

CAPACITY TABLE FOR OB AND CP PORTABLE STANDARD WATTHOUR METERS

Volts	FULL LOAD AMPERES						
	2-Capacity		3-Capacity				
120–240	1–5	1–10	1–5–15	1–5–25	1–5–50	1–10–25	1–10–50
240–480	1–5	1–10	1–5–15	1–5–25	1–5–50	1–10–25	1–10–50
	5-Capacity						
120–240	1–5–10–25–50						
240–480	1–5–10–25–50						

TABLE 16-S

TEST DATA FOR WESTINGHOUSE OB AND CP PORTABLE STANDARD WATTHOUR METERS

Volts	120 Volts						240 Volts					
Amperes	1	5	10	15	25	50	1	5	10	15	25	50
K_h	1/15	1/3	2/3	1	1 2/3	3 1/3	2/15	2/3	1 1/3	2	3 1/3	6 2/3

Volts	480 Volts					
Amperes	1	5	10	15	25	50
K_h	4/15	1 1/3	2 2/3	4	6 2/3	13 1/3

A voltage multiplier is available to make 120–240 Volt CP Portable standards suitable for testing at 480 or 600 volts as well as at rated voltages. These multipliers are connected in series with the potential circuit of the portable. Each one should be calibrated for the portable with which it is to be used.

TABLE 16-T

CONSTANTS FOR WESTINGHOUSE TYPE RO WATTHOUR DEMAND METERS

	100-volt, 2-wire, Single-phase				**200-volt, 2-wire, 100-200-volt, 3-wire, single-phase or 100-volt, polyphase**			
Rating in Amperes	**Watthour Constant (K_h)**	**Register Constant (K_r)**	**Register Ratio (R_r)**	**Demand Dial Full Scale Kilowatts**	**Watthour Constant (K_h)**	**Register Constant (K_r)**	**Register Ratio (R_r)**	**Demand Dial Full Scale Kilowatts**
5	$\frac{1}{3}$	1	4800	1	$\frac{2}{3}$	1	2400	2
10	$\frac{2}{3}$	1	2400	2	$1\frac{1}{3}$	1	1200	4
15	1	1	1600	3	2	1	800	6
20*	$1\frac{1}{3}$	1	1200	4	$2\frac{2}{3}$	1	600	8
25	$1\frac{2}{3}$	1	960	5	$3\frac{1}{3}$	1	480	10
40*	$2\frac{2}{3}$	1	600	8	$5\frac{1}{3}$	1	300	16
50	$3\frac{1}{3}$	1	480	10	$6\frac{2}{3}$	1	240	20
60*	4	1	400	12	8	1	200	24
75	5	1	320	15	10	1	160	30
80*	$5\frac{1}{3}$	1	300	16	$10\frac{2}{3}$†	1†	150†	32†
	200-volt, polyphase				**400-volt, polyphase**			
5	$1\frac{1}{3}$	1	1200	4	$2\frac{2}{3}$	1	600	8
10	$2\frac{2}{3}$	1	600	8	$5\frac{1}{3}$	1	300	16
15	4	1	400	12	8	1	200	24
20*	$5\frac{1}{4}$	1	300	16	$10\frac{2}{3}$	1	150	32
25	$6\frac{2}{3}$	1	240	20	$13\frac{1}{3}$	1	120	40
40*	$10\frac{2}{3}$	1	150	32	$21\frac{1}{3}$	10	750	64
50	$13\frac{1}{3}$	1	120	40	$26\frac{2}{3}$	10	600	80
60*	16	10	1000	48	32	10	500	96
75	20	10	800	60	40	10	400	120
80*	$21\frac{1}{3}$	10	750	64	$42\frac{2}{3}$	10	375	128

NOTE.—$R_g = R_r \times 6.25$, in which R_g = gear ratio $K_t = K_h \times 3600$, in which K_t = test constant

Numerical value of one revolution of first dial pointer, also value, of demand dial reading at full scale $= 10 \times K_r$

Multiplier for demand dial = Full scale kilowatts × 0.1

*Special rating.   †200-volt, 2-wire only.

TABLE 16-U
CONSTANTS FOR WESTINGHOUSE TYPE RA RECORDING DEMAND WATTHOUR METERS
2- OR 3-PHASE, 3-WIRE

Rating in Kw	Volts	Register Constant K_r	Watthour Constant K_h	Reg. Ratio R_r	Gear Ratio R_g	Full Load on Dem. Chart in Kw	Full Scale on Dem. Chart in Kw
1	100	1	2/3	3,000	15,000	1	1.5
2	200	1	1 1/3	1,500	7,500	2	3
4	400	1	2 2/3	750	3,750	4	6
5	500	1	3 1/3	600	3,000	5	7.5
3-phase, 4-wire							
1.5	100	1	1	2,000	10,000	1.5	2.25

NOTE:—All meters have 5-ampere current coils for use with instrument transformers.

For all ratings, the dials and demand scale are direct reading and the registration must be multiplied by the combined current and potential transformer ratios where used.

TABLE 16-V
WESTINGHOUSE CONTACT DEVICE RATIOS

Bracket Ratio Ratio — Rev. of disc to 1 Rev. of Cam Shaft	Rev. per hr. of Cam Shaft when Meter is running 25 rpm.
18	$83^{1}/_{3}$
$18^{3}/_{4}$	80
20	75
$22^{1}/_{2}$	$66^{2}/_{3}$
24	$62^{1}/_{2}$
25	60
30	50
36	$41^{2}/_{3}$
$37^{1}/_{2}$	40
40	$37^{1}/_{2}$
45	$33^{1}/_{3}$
50	30
$56^{1}/_{4}$	$26^{2}/_{3}$
60	25
75	20
90	$16^{2}/_{3}$
100	15
$112^{1}/_{2}$	$13^{1}/_{3}$
120	$12^{1}/_{2}$
150	10
180	$8^{1}/_{3}$
225	$6^{2}/_{3}$
300	5
360	$4^{1}/_{6}$

TABLE 16-W

REGISTER AND TEST CONSTANTS FOR WESTINGHOUSE RECORDING AND INDICATING DEMAND METERS

AMPS	VOLTS	Watt-hour Constant K_h†	Register Constant K_r†	Register Ratio R_r	Gear Ratio R_g	Kw or Kva Rating*†	Full Scale on Demand Chart or Dial Kw† or Kva†
RI-2, RI-7, RI-10 Meters							
2.5	120	1/3	1	6,000	30,000	.6	1.5
2.5	240	2/3	1	3,000	15,000	1.2	3.0
2.5	480	1 1/3	1	1,500	7,500	2.4	6.0
5.0	120	2/3	1	3,000	15,000	1.2	1.5
5.0	240	1 1/3	1	1,500	7,500	2.4	3.0
5.0	480	2 2/3	1	750	3,750	4.8	6.0
15.0	120	2	3	3,000	15,000	3.6	4.5‡
15.0	240	4	3	1,500	7,500	7.2	9.0‡
15.0	480	8	3	750	3,750	14.4	18.0‡
50.0	120	6 2/3	10	3,000	15,000	12.0	15.0‡
50.0	240	13 1/3	10	1,500	7,500	24.0	30.0‡
50.0	480	26 2/3	10	750	3,750	48.0	60.0‡
RI-3, RI-4, RI-6, RI-8, RI-9							
2.5	120	1/2	1	4,000	20,000	.9	2.25
2.5	240	1	1	2,000	10,000	1.8	4.5
2.5	480	2	1	1,000	5,000	3.6	9.0
5.0	120	1	1	2,000	10,000	1.8	2.25
5.0	240	2	1	1,000	5,000	3.6	4.5
5.0	480	4	1	500	2,500	7.2	9.0
15.0	120	3	3	2,000	10,000	5.4	6.75‡
15.0	240	6	3	1,000	5,000	10.8	13.5‡
15.0	480	12	3	500	2,500	21.6	27.0‡
50.0	120	10	10	2,000	10,000	18.0	22.5‡
50.0	240	20	10	1,000	5,000	36.0	45.0‡
50.0	480	40	10	500	2,500	72.0	90.0‡
RI-38 Meter							
2.5	120	1	1	2,000	10,000	1.8	4.5
2.5	240	2	1	1,000	5,000	3.6	9.0
2.5	480	4	1	500	2,500	7.2	18.0
5.0	120	2	1	1,000	5,000	3.6	4.5
5.0	240	4	1	500	2,500	7.2	9.0
5.0	480	8	1	250	1,250	14.4	18.0
15.0	120	6	3	1,000	5,000	10.8	13.5‡
15.0	240	12	3	500	2,500	21.6	27.0‡
15.0	480	24	3	250	1,250	43.2	54.0‡
50.0	120	20	10	1,000	5,000	36.0	45.0‡
50.0	240	40	10	500	2,500	72.0	90.0‡
50.0	480	80	10	250	1,250	144.0	180.0‡
RI-32 Meter							
2.5	120	2/3	1	3,000	15,000	1.2	3.0
2.5	240	1 1/3	1	1,500	7,500	2.4	6.0
2.5	480	2 2/3	1	750	3,750	4.8	12.0
5.0	120	1 1/3	1	1,500	7,500	2.4	3.0
5.0	240	2 2/3	1	750	3,750	4.8	6.0
5.0	480	5 1/3	1	375	1,875	9.6	12.0
15.0	120	4	3	1,500	7,500	7.2	9.0‡
15.0	240	8	3	750	3,750	14.4	18.0‡
15.0	480	16	3	375	1,875	28.8	36.0‡
50.0	120	13 1/3	10	1,500	7,500	24.0	30.0‡
50.0	240	26 2/3	10	750	3,750	48.0	60.0‡
50.0	480	53 1/3	10	375	1.875	96.0	120.0‡

TABLE 16-W (Continued)—

WESTINGHOUSE Register and Test Constants

AMPS	VOLTS	Watt-hour Constant K_h†	Register Constant K_r†	Register Ratio R_r	Gear Ratio R_g	KW or KVA Rating*†	Full Scale on Demand Chart or Dial KW† or KVA†
RKA Meter							
5.0	120	1/3	1	7,500	30,000	.6	1.5
5.0	240	2/3	1	3,750	15,000	1.2	3.0
5.0	480	1 1/3	1	1,875	7,500	2.4	6.0
15.0	120	1	1	2,500	10,000	1.8	4.5‡
15.0	240	2	1	1,250	5,000	3.6	9.0‡
15.0	480	4	1	625	2,500	7.2	18.0‡
50.0	120	3 1/3	1	750	3,000	6.0	15.0‡
50.0	240	6 2/3	1	375	1,500	12.0	30.0‡
50.0	480	13 1/3	10	1,875	7,500	24.0	60.0‡
RK-2, RK-5, RK-7 and RK-10							
2.5	120	1/3	1	3,600	30,000	.6	1.5
2.5	240	2/3	1	1,800	15,000	1.2	3.0
2.5	480	1 1/3	1	900	7,500	2.4	6.0
5.0	120	2/3	1	1,800	15,000	1.2	3.0
5.0	240	1 1/3	1	900	7,500	2.4	6.0
5.0	480	2 2/3	1	450	3,750	4.8	12.0
15.0	120	2	3	1,800	15,000	3.6	9.0‡
15.0	240	4	3	900	7,500	7.2	18.0‡
15.0	480	8	3	450	3,750	14.4	36.0‡
50.0	120	6 2/3	10	1,800	15,000	12.0	30.0‡
50.0	240	13 1/3	10	900	7,500	24.0	60.0‡
50.0	480	26 2/3	10	450	3,750	48.0	120.0‡
RK-3, RK-4, RK-6, RK-8, RK-9							
2.5	120	1/2	1	2,400	20,000	0.9	2.25
2.5	240	1	1	1,200	10,000	1.8	4.5
2.5	480	2	1	600	5,000	3.6	9.0
5.0	120	1	1	1,200	10,000	1.8	4.5
5.0	240	2	1	600	5,000	3.6	9.0
5.0	480	4	1	300	2,500	7.2	18.0
15.0	120	3	3	1,200	10,000	5.4	13.5‡
15.0	240	6	3	600	5,000	10.8	27.0‡
15.0	480	12	3	300	2,500	21.6	54.0‡
50.0	120	10	10	1,200	10,000	18.0	45.0‡
50.0	240	20	10	600	5,000	36.0	90.0‡
50.0	480	40	10	300	2,500	72.0	180.0‡
R-2, R-7, R-10, R-22, R-27, R-42 and RB 2-Element Meters							
2.5	120	1/3	1	3,600	30,000	0.6	1.5
2.5	240	2/3	1	1,800	15,000	1.2	3.0
2.5	480	1 1/3	1	900	7,500	2.4	6.0
5.0	120	2/3	1	1,800	15,000	1.2	1.5
5.0	240	1 1/3	1	900	7,500	2.4	3.0
5.0	480	2 2/3	1	450	3,750	4.8	6.0
15.0	120	2	3	1,800	15,000	3.6	4.5‡
15.0	240	4	3	900	7,500	7.2	9.0‡
15.0	480	8	3	450	3,750	14.4	18.0‡
50.0	120	6 2/3	10	1,800	15,000	12.0	15.0‡
50.0	240	13 1/3	10	900	7,500	24.0	30.0‡
50.0	480	26 2/3	10	450	3,750	36.0	60.0‡

TABLE 16-W (Continued)—

WESTINGHOUSE Register and Test Constants

AMPS	VOLTS	Watt-hour Constant K_H†	Register Constant K_R†	Register Ratio R_s	Gear Ratio R_g	KW or KVA Rating*†	Full Scale on Demand Chart or Dial KW† or KVA†
R-3, R-4, R-6, R-8, R-9, R-23, R-28, R-29, R-43 RB 2½-, and 3-Element Meters							
2.5	120	1/2	1	2,400	20,000	0.9	2.25
2.5	240	1	1	1,200	10,000	1.8	4.5
2.5	480	2	1	600	5,000	3.6	9.0
5.0	120	1	1	1,200	10,000	1.8	2.25
5.0	240	2	1	600	5,000	3.6	4.5
5.0	480	4	1	300	2,500	7.2	9.0
15.0	120	3	3	1,200	10,000	5.4	6.75‡
15.0	240	6	3	600	5,000	10.8	13.5‡
15.0	480	12	3	300	2,500	21.6	27.0‡
50.0	120	10	10	1,200	10,000	18.0	22.5‡
50.0	240	20	10	600	5,000	36.0	45.0‡
50.0	480	40	10	300	2,500	72.0	90.0‡
R-32 and R-52							
2.5	120	2/3	1	3,000	15,000	1.2	3.0
2.5	240	1 1/3	1	1,500	7,500	2.4	6.0
2.5	480	2 2/3	1	750	3,750	4.8	12.0
5.0	120	1 1/3	1	1,500	7,500	2.4	3.0
5.0	240	2 2/3	1	750	3,750	4.8	6.0
5.0	480	5 1/3	1	375	1,875	9.6	12.0
15.0	120	4	3	1,500	7,500	7.2	9.0‡
15.0	240	8	3	750	3,750	14.4	18.0‡
15.0	480	16	3	375	1,875	28.8	36.0‡
50.0	120	13 1/3	10	1,500	7,500	24.0	30.0‡
50.0	240	26 2/3	10	750	3,750	48.0	60.0‡
50.0	480	55 1/3	10	375	1,875	96.0	120.0‡

* Based on 120 volts or multiples thereof.

† For transformer type meters multiply values given by the product of the transformer ratios.

‡ Figure given includes multiplier.

SECTION 17

REGISTER CONSTANTS AND DEMAND SCALES

Considerable progress has been made in recent years to bring about standardization and uniformity of register constants and demand scales for watthour meters, combined watthour and demand meters, and external demand meters.

Some of the more important reasons for accomplishing this objective are to insure high enough register ratios to prevent kilowatthour registers from making a complete turnover within the span of a single billing period; to simplify and reduce the cost of manufacturing and stocking of equipment, and to provide for ease of reading of demand registers and meters.

REGISTER CONSTANTS

In order to obtain full advantage of the overload feature of modern watthour meters, the meters must be applied to operate over wide load limits. However, such permissible heavy overloads should not be allowed to cause a complete register turnover within a normal billing period. This factor has become of greater importance recently because of the trend toward longer billing periods.

The use of direct-reading kilowatthour registers (register constant of 1) is desirable except where there are offsetting disadvantages, since multiplying constants other than 1 present a potential source of error in reading and billing operations. In those cases, however, where the use of a direct-reading register might cause a complete register turnover within a normal billing period, it is necessary to use a register of a higher ratio with a register constant.

Table 17-A shows the recommended register constants for standard four-dial registers. For the purpose of eliminating register constants of 10, standard five-dial registers may be used which will provide a register constant of 1 for those meters listed with a register constant of 10.

In some cases it may be deemed desirable to eliminate the use of registers of different ratios for meters used in connection with instrument transformers. This may be accomplished by using, for all instrument transformer meters, a register of the ratio which would be required if the meter were considered as a self-contained meter.

Where such a register is used for a meter connected to current transformers only, the register constant would be equal to the current transformer ratio. Where the meter is connected to both current and potential transformers, the register constant would be equal to the product of the current transformer ratio and the potential transformer ratio.

The transformer ratio is obtained by dividing the rated primary current or voltage by the rated secondary current or voltage.

DEMAND SCALES

Indicating Demand Registers

Demand scales for indicating demand registers have been made in a great variety of forms. Generally speaking, demand registers have been manufactured in the past in the same ratios as kilowatthour registers, the register constant normally applied to the kilowatthour reading also being applied to the reading of the demand scale.

It has become apparent in recent years, however, that demand registers should be manufactured in as few ratios as possible in order to simplify operations such as handling, stocking, maintenance,. replacement, etc. In order to bring about this simplification, specifications for indicating demand

TABLE 17-A
REGISTER CONSTANTS

Ampere Rating	120 Volts			240 Volts			480 Volts
	1-Element	2-Element	3-Element	1-Element	2-Element	3-Element	2-Element
Self-Contained Meters							
5	1	1	1	1	1	1	1
10	1	1	1	1	1	10	10
15	1	1	1	1	10	10	10
25	1	1	10	1	10	10	10
50	1	10	10	10	10	10	10
75	1	10	10	10	10	10	10
Current Transformer Meters							
100	1	10	10	10	10	10	10
120	10	10	10	10	10	10	10
150	10	10	10	10	10	10	100
160	10	10	10	10	10	10	100
200	10	10	10	10	10	100	100
250	10	10	10	10	10	100	100
300	10	10	10	10	100	100	100
400	10	10	100	10	100	100	100
500	10	10	100	10	100	100	100
600	10	100	100	100	100	100	100
750	10	100	100	100	100	100	100
800	10	100	100	100	100	100	100
1000	10	100	100	100	100	100	100
1200	100	100	100	100	100	100	100
1600	100	100	100	100	100	100	1000
2000	100	100	100	100	100	1000	1000
2400	100	100	100	100	100	1000	1000
5000	100	100	1000	100	1000	1000	1000
10000	100	1000	1000	1000	1000	1000	1000

registers recently adopted by the EEI and AEIC have standardized on the register ratios given in Table 17-B.

The demand registers in Table 17-B are for use as universal registers. Whichever register is selected for use as universal may be mounted on any type of alternating current self-contained or current transformer watthour meter which is designed to accommodate it regardless of the ampere, voltage or element rating of the watthour meter. The multiplying constant to be applied to the kwhr and kw readings of the watthour meter on which the register is mounted is derived as follows:

For 0.6 kva register

$$\text{multiplying constant} = \frac{\text{kva rating of meter*}}{0.6}$$

For 1.2 kva register

$$\text{multiplying constant} = \frac{\text{kva rating of meter*}}{1.2}$$

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* Does not include all superseded types of meters.

TABLE 17-B
REGISTER RATIOS

Register Rating Kva	Register Ratios					Full Scale Value	
	Duncan Electric Manufacturing Company	General Electric Company	Sangamo Electric Company		Westinghouse Electric Corp.	Class 1	Class 2
			Single Element	Multi Element			
0.6	400	166⅔	166⅔	1500	3600	1.0 kw	2.0 kw
1.2	200	83⅓	83⅓	750	1800	2.0 kw	4.0 kw

The full scale value of the Class 1 demand register is 166 2/3% of the kva rating of the watthour meter on which it is mounted, and that of the Class 2 demand register is 333 1/3%, the kva rating of the watthour meter being derived as follows:

$$\text{kva rating} = \frac{E \times I \times \text{No. of Elements*}}{1000}$$

where

E (self-contained meters) = 120 or multiples thereof

E (potential transformer meters) = 120 × potential transformer ratio

I (self-contained meters)** = ampere rating of meter

I (current transformer meters) = ampere rating of meter (2½ or 5) × current transformer ratio

By restricting the use of demand registers to any one of the four combinations set up in Table 17-B: 0.6 kva register Class 1, 0.6 kva register Class 2, 1.2 kva register Class 1, and 1.2 kva register Class 2, handling operations are simplified and the same identical type of demand scale is provided for all types and capacities of watthour meters, which makes for ease of reading. On the other hand, it must be recognized that constants other than 1, 10 and 100 will be introduced, and precautions must be taken to guard against errors in billing operations.

Indicating Thermal Watt Demand Meters

Progress has been made also in bringing about uniformity of demand scales for thermal demand meters. Specifications recently adopted by the EEI and AEIC have standardized on three classes of scales, the full scale values being based upon the kva rating of the demand element.

Class 1—166 2/3%
Class 2—333 1/3%
Class 3—200%

The full scale values for these scale classes are given in Table 17-C, and the number of scale divisions is shown in Table 17-D.

It is recommended that all purchasers of meters adopt these standards and adhere to them with the prospect that manufacturing costs, and hence the price of meters, might be reduced as the demands on the manufacturers for a large variety of types and sizes of equipment become less prevalent.

For the latest information on standards in connection with register constants and demand scales, reference should be made to the latest revisions of Specifications MS-1, MS-4, and MS-5, jointly adopted by the Edison Electric Institute and the Association of Edison Illuminating Companies.

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* 2-element, 3-phase, 4-wire wye meters considered as having 3 elements.

** 12.5 amperes for 15-ampere General Electric Co. Type I-30 watthour meter.

TABLE 17-C
FULL SCALE VALUE IN KILOWATTS

Ampere Rating	Class	120 V. 1-Element	240 V. 1-Element; 120 V. 2-Element	120 V. 3-Element	240 V. 2-Element	240 V. 3-Element	480 V. 2-Element
2.5 C.T.	2	1.0	2.0	3.0	4.0	6.0	8.0
5 C.T.	1	1.0	2.0	3.0	4.0	6.0	8.0
15	2	6.0	12.0	18.0	24.0	36.0	48.0
50	3	12.0	24.0	36.0	48.0	72.0	96.0
Optional Standards							
2.5 C.T.	1	0.5	1.0	1.5	2.0	3.0	4.0
15	3	3.6	7.2	10.8	14.4	21.6	28.8

TABLE 17-D
SCALE DIVISIONS

Kw Full Scale	Kw per Division	Number of Divisions			
		Total	M	I	S
0.5	0.01	50	5	2	5
1.0*	0.01	100	10	2	5
1.5	0.02	75	15	0	5
2.0	0.02	100	20	0	5
3.0	0.05	60	6	5	2
3.6	0.05	72	7	5	2 + 2
4.0	0.05	80	8	5	2
6.0	0.1	60	6	2	5
7.2	0.1	72	7	2	5 + 2
8.0	0.1	80	8	2	5
10.8	0.2	54	10	0	5 + 4
12.0	0.2	60	12	0	5
14.4	0.2	72	14	0	5 + 2
18.0	0.2	90	18	0	5
21.6†	0.5	43	21	0	2 + 1
24.0	0.5	48	24	0	2
28.8†	0.5	58	29	0	2
36.0	0.5	72	7	5	2 + 2
48.0	0.5	96	9	5	2 + 6
72.0	1.0	72	7	2	5 + 2
96.0	1.0	96	9	2	5 + 6
100.0‡	1.0	100	10	2	5

* Universal and direct reading scale
† Scale length does not give exact value
‡ Universal scale only

M—Main Divisions
I—Intermediate Divisions
S—Sub Divisions

SECTION 18

TECHNICAL DATA AND TABLES

The data contained in this section have been compiled from various sources and include a number of physical, mathematical, and general tables which are often useful in conjunction with the electrical data given elsewhere in the book.

The list of abbreviations and the tabular matter is, as far as can be determined, in accordance with the standards promulgated by the various technical associations and committees.

Some data are included covering practical electrical calculations such as wiring and motor calculations, which may be of value to the metermen in determining the proper size and rating of equipment to be installed under specific conditions.

ABBREVIATIONS

The following list consists of the more commonly used technical terms and their abbreviations. Most of the abbreviations given have been approved by the American Standards Association. The general omission of periods after abbreviations has been recommended not only as a measure of economy but also to avoid confusion which has been found to result from attempts to employ abbreviations for the names of metric units without

TABLE 18-A

COMMONLY USED ABBREVIATIONS

Name	Abbreviation	Name	Abbreviation
alternating-current (as adjective)	a-c	kilovar-hour	kvarhr or kvarh
ampere	amp or a	kilovolt	kv
ampere-hour	amp-hr	kilovolt-ampere	kva
brake horsepower	bhp	kilovolt-ampere-hour	kvahr or kvah
British thermal unit	Btu	kilowatt	kw
candlepower	cp	kilowatthour	kwhr or kwh
centimeter	cm	magnetomotive force	mmf
centimeter-gram-second	cgs	meter (length)	m
circular mils	cir mils	microfarad	μf, mfd or mu f
counter electromotive force	cemf	mile	spell out
cubic	cu	milliampere	ma
degree	deg (°)	milligram	mg
degree centigrade	C	millihenry	mh
degree Fahrenheit	F	millimeter	mm
diameter	diam	millimeter-gram	mm-g
direct-current (as adjective)	d-c	millivolt	mv
electromotive force	emf	minute	min
foot	ft	minute (angular measure)	′
foot-pound	ft-lb	ohm	spell out or Ω
gallon	gal	pound	lb
grain	spell out	power factor	spell out or pf
gram	g	revolutions per minute	rpm
gram-calorie	g-cal	root-mean-square	rms
horsepower	hp	second	sec
hour	hr	second (angular measure)	″
inch	in.	square	sq
indicated horsepower	ihp	var (reactive volt-ampere)	spell out
kilogram	kg	volt	v
kilogram-calorie	kg-cal	volt-ampere	va
kilogram-meter	kg-m	watt	w
kilometer	km	watthour	whr or wh
kilovar	kvar	yard	yd

periods and abbreviations for the names of English units with periods in the same publication.

Abbreviations are used in the singular form for both singular and plural quantities.

FUNDAMENTAL UNITS

The electrical units are derived from the following mechanical units:

The centimeter, the unit of length.

The gram, the unit of mass.

The second, the unit of time.

The centimeter equals 0.3937 of an inch, or one thousand-millionth part of a quadrant of the earth.

The gram is equal to 15.432 grains, the mass of a cubic centimeter of water at 4 degrees centigrade.

The second is the time of one swing of a pendulum, making 86,464.09 swings per day, or the 1/86,400 part of a mean solar day.

ELECTRICAL UNITS

Watts = unit of electric power = hp × 745.65
Watts = amperes × volts × power factor
Watts = foot-pounds per second ÷ 1.356.
Joules, W = work done = watts × seconds.

1 kilowatthour = 3412 Btu
1 kilowatthour = 2,654,536 ft-lb
1 kilowatthour = 3.53 lb water evaporated at 212 F
1 kilowatthour = 22.8 lb water raised from 62 to 212 F
1 kilowatthour = 0.235 lb carbon oxidized at 100 per cent efficiency.

MEASUREMENTS

Circumference of circle whose diameter is 1 = π = 3.14159265.
Circumference of any circle = diameter × π.
Area of any circle = (radius)^2 × π = (diameter)^2 × 0.7854.
Surface of sphere = (diameter)^2 × π = circumference × diameter.
Volume of sphere = (diameter)^3 × 0.5236 = surface × 1/6 diameter.
Area of an ellipse = long diameter × short diameter × 0.7854.
$\pi^2 = 9.8696$; $\sqrt{\pi} = 1.772454$; $\pi/4 = 0.7854$.
$1/\pi = 0.31831$; $\log \pi = 0.4971499$.
Basis of natural log $\epsilon = 2.7183$; $\log \epsilon = 0.43429$.
$\text{Log}_\epsilon n = 2.3026 \log_{10} n$.

CONVERSION FACTORS

1 lb per sq in. = 144 lb per sq ft
1 lb per sq in. = 51.7116 mm of mercury
1 lb per sq in. = 2.30665 ft of water
1 lb per sq in. = 0.072 ton (short) per sq ft
1 lb per sq in. = 0.0680415 atmosphere.
1 mile = 320 rods = 1760 yd = 5280 ft = 63,360 in.

1728 cu in. = 1 cu ft.
231 cu in. = 1 liquid gallon = 0.134 cu ft.
1 lb avoirdupois = 7000 grains = 453.6 grams.
The angle of which the arc is equal to the radius, a radian = 57.2958 deg.
1 Btu of heat = 778 ft-lb.
1 calorie of heat = 426.6 kg-m = 3.968 Btu.
1 cu ft of water weighs 62.355 lb at 62 F.
1 cu ft of air weighs 0.0807 lb at 32 F and 1 atmosphere.
1 cu ft of hydrogen weighs 0.00557 lb.

1 ft-lb = 1.3562×10^7 ergs.
1 horsepower hour = $33{,}000 \times 60$ ft-lbs.
1 horsepower = 33,000 ft-lb per min = 550 ft-lb per second = 745.65 watts = 2545 Btu per hour.

Acceleration of gravity (g) = 32.2 ft per sec per sec = 980 cm per sec per sec.

1 atmosphere = 14.7 pounds per sq in.
= 2116 pounds per sq ft.
= 760 mm of mercury.

Velocity of sound at 0 C in dry air = 332.4 meters per second.
= 1091 ft per second.
Velocity of light in vacuum = 299,776 km per second.
= 186,251 miles per second.

Specific heat of air at constant pressure = 0.237.
A column of water 2.3 ft high corresponds to a pressure of 1 lb per sq in.
Latent heat of ice = 79.24 calories per gram.
Latent heat of water = 535.9 calories per gram.

METRIC—ENGLISH EQUIVALENTS

Linear Measures

1 meter = 39.37 in. = 3.281 ft = 1.094 yards.
1 centimeter = 1/100 meter = 0.3937 inch.
1 millimeter (mm) = 0.03937 inch = 39.37 mils.
1 inch = 25.3997 mm = 0.083 ft = 2.54 cm.
1 kilometer = 1000 meters = 3281 ft = 0.6213 mile.
For the purpose of memory, a meter may be considered as 3 ft 3 1/3 in.

Surface Measures

1 centare (1 sq m) = 1550 sq in. = 10.764 sq ft.
1 square centimeter = 0.155 sq in. = 197,300 circular mils.
1 square millimeter = 0.00155 sq in. = 1973 circular mils.
1 square inch = 6.451 sq cm = 0.0069 sq ft.
1 square foot = 929.03 sq cm = 0.0929 sq m.

Weights

1 milligram (1/1000 gram) = 0.0154 grain.
1 gram = 15.432 grains.
1 kilogram (1,000 grams) = 2.2046 pounds.

Liquid Measures

1 liter = 1.0567 quarts = 0.2642 gallon = 33.8 fluid ounces.
1 hectoliter (100 liters) = 26.418 gallons.
1 quart = 16 fluid ounces = 2 pints = ¼ gallon = 0.9463 liter.

Volumes

1 cubic centimeter = 0.0610 cu in.
1 cubic meter = 35.3145 cu ft = 1.3079 cu yd.
1 cubic inch = 16.3872 cu cm.
1 cubic foot = 0.0283 cu m.
1 cubic yard = 0.7646 cu m.

TABLE 18-B

COMPARISON OF THERMOMETRICAL SCALES

Cent. or Celsius	Fahr.	Cent. or Celsius	Fahr.	Cent. or Celsius	Fahr.	Cent. or Celsius	Fahr.	Cent. or Celsius	Fahr.	Cent. or Celsius	Fahr.
0	32.0	29	84.2	58	136.4	87	188.6	116	240.8	145	293.0
1	33.8	30	86.0	59	138.2	88	190.4	117	242.6	146	294.8
2	35.6	31	87.8	60	140.0	89	192.2	118	244.4	147	296.6
3	37.4	32	89.6	61	141.8	90	194.0	119	246.2	148	298.4
4	39.2	33	91.4	62	143.6	91	195.8	120	248.0	149	300.2
5	41.0	34	93.2	63	145.4	92	197.6	121	249.8	150	302.0
6	42.8	35	95.0	64	147.2	93	199.4	122	251.6	151	303.8
7	44.6	36	96.8	65	149.0	94	201.2	123	253.4	152	305.6
8	46.4	37	98.6	66	150.8	95	203.0	124	255.2	153	307.4
9	48.2	38	100.4	67	152.6	96	204.8	125	257.0	154	309.2
10	50.0	39	102.2	68	154.4	97	206.6	126	258.8	155	311.0
11	51.8	40	104.0	69	156.2	98	208.4	127	260.6	156	312.8
12	53.6	41	105.8	70	158.0	99	210.2	128	262.4	157	314.6
13	55.4	42	107.6	71	159.8	100	212.0	129	264.2	158	316.4
14	57.2	43	109.4	72	161.6	101	213.8	130	266.0	159	318.2
15	59.0	44	111.2	73	163.4	102	215.6	131	267.8	160	320.0
16	60.8	45	113.0	74	165.2	103	217.4	132	269.6	161	321.8
17	62.6	46	114.8	75	167.0	104	219.2	133	271.4	162	323.6
18	64.4	47	116.6	76	168.8	105	221.0	134	273.2	163	325.4
19	66.2	48	118.4	77	170.6	106	222.8	135	275.0	164	327.2
20	68.0	49	120.2	78	172.4	107	224.6	136	276.8	165	329.0
21	69.8	50	122.0	79	174.2	108	226.4	137	278.6	166	330.8
22	71.6	51	123.8	80	176.0	109	228.2	138	280.4	167	332.6
23	73.4	52	125.6	81	177.8	110	230.0	139	282.2	168	334.4
24	75.2	53	127.4	82	179.6	111	231.8	140	284.0	169	336.2
25	77.0	54	129.2	83	181.4	112	233.6	141	285.8	170	338.0
26	78.8	55	131.0	84	183.2	113	235.4	142	287.6		
27	80.6	56	132.8	85	185.0	114	237.2	143	289.4		
28	82.4	57	134.6	86	186.8	115	239.0	144	291.2		

TABLE 18-C

DECIMAL EQUIVALENTS

Fraction	Decimal	Fraction	Decimal	Fraction	Decimal	Fraction	Decimal	Fraction	Decimal	Fraction	Decimal	Fraction	Decimal	Fraction	Decimal
	0.0078		.1328		0.2578		.3828		0.5078		.6328		0.7578		.8828
1/64	**.0156**	9/64	**.1406**	17/64	**.2656**	25/64	**.3906**	33/64	**.5156**	41/64	**.6406**	49/64	**.7656**	57/64	**.8906**
	.0234		.1484		.2734		.3984		.5234		.6484		.7734		.8984
1/32	**.0313**	5/32	**.1563**	9/32	**.2813**	13/32	**.4063**	17/32	**.5313**	21/32	**.6563**	25/32	**.7813**	29/32	**.9063**
	.0391		.1641		.2891		.4141		.5391		.6641		.7891		.9141
3/64	**.0469**	11/64	**.1719**	19/64	**.2969**	27/64	**.4219**	35/64	**.5469**	43/64	**.6719**	51/64	**.7969**	59/64	**.9219**
	.0547		.1797		.3047		.4297		.5547		.6797		.8047		.9297
1/16	**.0625**	3/16	**.1875**	5/16	**.3125**	7/16	**.4375**	9/16	**.5625**	11/16	**.6875**	13/16	**.8125**	15/16	**.9375**
	.0703		.1953		.3203		.4453		.5703		.6953		.8203		.9453
5/64	**.0781**	13/64	**.2031**	21/64	**.3281**	29/64	**.4531**	37/64	**.5781**	45/64	**.7031**	53/64	**.8281**	61/64	**.9531**
	.0859		.2109		.3359		.4609		.5859		.7109		.8359		.9609
3/32	**.0938**	7/32	**.2188**	11/32	**.3438**	15/32	**.4688**	19/32	**.5938**	23/32	**.7188**	27/32	**.8438**	31/32	**.9688**
	.1016		.2266		.3516		.4766		.6016		.7266		.8516		.9766
7/64	**.1094**	15/64	**.2344**	23/64	**.3594**	31/64	**.4844**	39/64	**.6094**	47/64	**.7344**	55/64	**.8594**	63/64	**.9844**
	.1172		.2422		.3672		.4922		.6172		.7422		.8672		.9922
1/8	**.1250**	1/4	**.2500**	3/8	**.3750**	1/2	**.5000**	5/8	**.6250**	3/4	**.7500**	7/8	**.8750**	1	**1.0000**
			.2578				.5078				.7578				

DECIMAL EQUIVALENTS OF 64ths

The decimal fractions printed in bold-face type give the exact value of the corresponding fraction to the fourth decimal place. A given decimal fraction is rarely exactly equal to any of these values, and the numbers in light-face type show which common fraction is nearest to the given decimal. Thus, lay off the fraction 0.1330 in 64ths. The nearest decimal fractions are 0.1250 and 0.1406. The value of any fraction in light-face type is the mean of the two adjacent fractions. In this instance the mean fraction is 0.1328, and as 0.1330 is greater than this, 0.1406 or 9/64 will be chosen. In the same manner the nearest 64ths corresponding to the decimal fractions 0.3670 and 0.8979 are found to be 23/64 and 57/64, respectively.

TEMPERATURE

Degrees Centigrade—To convert into degrees Fahrenheit, multiply by 9/5 and add 32.

To convert into degrees Réaumur multiply by 4/5.

To convert into absolute scale, add 273.

Degrees Fahrenheit—To convert into degrees centigrade, subtract 32, and then multiply by 5/9, being careful about the signs when the reading is below the melting point of ice.

To convert into degrees Réaumur, subtract 32 and multiply by 4/9.

To convert into absolute scale, subtract 32, then multiply by 5/9 and add 273; or multiply by 5, add 2297, and divide by 9.

TABLE 18-D

GREEK ALPHABET

Name	Large	Small	To Designate	Name	Large	Small	To Designate
alpha..	Α	α	angles, coefficients	lambda.	Λ	λ	conductivity
beta...	Β	β	angles, coefficients	mu....	Μ	μ	permeability prefix micro
gamma.	Γ	γ	specific gravity, conductivity, angles	nu.....	Ν	ν	reluctivity
delta...	Δ	δ	density, variation	xi......	Ξ	ξ	output coefficient
epsilon	Ε	ε	base of hyperbolic logarithms	omicron	Ο	ο	
zeta...	Ζ	ζ	co-ordinates, coefficients	pi......	Π	π	circumference + diameter
eta....	Η	η	hysteresis (Steinmetz) coefficient, efficiency	rho....	Ρ	ρ	resistivity
theta..	Θ	θ	angular phase displacement, time constant, time-phase displacement	sigma..	Σ	σ	(cap.), summation; leakage coefficient
iota....	Ι	ι		tau....	Τ	τ	time-phase displacement
kappa..	Κ	κ	dielectric constant, susceptibility	upsilon.	Υ	υ	
				phi	Φ	φ	magnetic flux
				chi....	Χ	χ	
				psi.....	Ψ	ψ	angular velocity in time, electrostatic flux
				omega..	Ω	ω	(small), angular velocity in space

SYMBOLS OF UNITS

Symbol	*Quantity*	*Equation*	*Practical Units* *English*	 *Cgs*
l	Length		Foot Inch	Centimeter
M	Mass		Pound	Gram
t	Time		Minute Second	Second
Geometrical				
A	Area	$A = l_1 l_2$	Square foot Square inch	Square Centimeter
V	Volume	$V = l_1 l_2 l_3$	Cubic foot Cubic inch	Cubic Centimeter

Mechanical

Symbol	*Quantity*	*Equation*	*Practical Units*
v	Linear velocity	$v = \frac{d\,l}{d\,T}$	Feet per minute Feet per second
ω	Angular velocity	$\omega = \frac{d\Theta}{d\,t}$	Revolutions per minute
a	Acceleration	$a = \frac{d\,v}{d\,T}$	Feet per second per second
F	Force	$\mathbf{F} = M\,a$	Pound
W	Energy	$W = \mathbf{F}\,l$	Foot-pound Horsepower hour
P	Power	$P = \frac{d\,W}{d\,t}$	Footpounds per minute Horsepower
η	Efficiency	$\eta = \frac{\text{output}}{\text{input}}$	

Magnetic

$\mathbf{H}$	Field intensity	$\mathbf{H} = \frac{4\,\pi\,N\,I}{10\,l}$	Gilberts per cm
Φ	Flux	$\Phi = \mu\,H\,A$	Maxwell
$\mathbf{B}$	Flux density	$\mathbf{B} = \frac{\Phi}{A}$	Gauss
$\mathcal{F}$	Magnetomotive force	$\mathcal{F} = \frac{4\,\pi\,N\,I}{10}$	Gilbert
ν	Reluctivity	$\nu = \frac{1}{\mu}$	Oersted-centimeter
$\mathcal{R}$	Reluctance	$\mathcal{R} = \nu\frac{l}{A}$ $\mathcal{R} = \frac{\mathcal{F}}{\phi}$	Oersted
μ	Permeability	$\mu = \frac{\mathbf{B}}{\mathbf{H}}$	
$\mathcal{P}$	Permeance	$\mathcal{P} = \frac{1}{\mathcal{R}}$	
W	Magnetic energy	$W = \mathcal{F}\Phi$	Erg

Electrical

I, i	Current	$I = \frac{E}{Z}$ $I = \frac{E}{R}$ $i = \frac{dq}{dt}$	Ampere
	Current density	$= \frac{I}{A}$	Amperes per square centimeter

Symbol	*Quantity*	*Equation*	*Practical Unit*
Q, q	Quantity	$Q = \int i\,dt$	Coulomb Ampere-hour
R, r	Resistance	$R = \frac{P}{I^2}$ $R = \frac{E}{I}$	Ohm
E, e	Electromotive force	$E = IZ$ $E = IR$ $E = \frac{W}{I \cos \theta}$	Volt
ρ	Resistivity	$\rho = R \frac{\text{area}}{\text{length}}$	Ohm-centimeter Ohm/mil-ft.
C	Capacity	$C = \frac{Q}{E}$	Farad Microfarad
G, g	Conductance	$G = \frac{1}{R}$	Mho
B, b	Susceptance	$B = \frac{1}{X}$	Mho
Y	Admittance	$Y = \sqrt{G^2 + B^2} = \frac{1}{Z}$ Mho	
γ	Conductivity	$\gamma = \frac{1}{\rho}$	Mhos per centimeter
f	Frequency	$f = \frac{p\,n}{2 \times 60}$	Cycles per second
p	Number of poles		
n	Revolutions per minute		
W	Electric energy	$W = \int i^2 r\,dt$ $= \int P\,dt$	
ω	Angular velocity	$\omega = 2\pi f$	
L	Coefficient of self induction	$L = \frac{N\phi}{I \times 10^8}$	Henry
X_L	Inductive reactance	$X_L = 2\pi f L$	Ohm
X_c	Capacitive reactance	$X_c = \frac{1}{2\pi f C}$	Ohm
X, x	Reactance	$X = X_L - X_c$	Ohm
Z, z	Impedance	$Z = \sqrt{R^2 + X^2}$ $= \frac{E}{I}$	Ohm
P, p	Electric power	$P = EIF_p$	Watt
P_S	Apparent power	$P_S = EI$	Volt-ampere

Symbol	*Quantity*	*Equation*	*Practical Unit*
Q, P_q	Reactive power	$P_q = EIF_q$	Var
F_p	Power factor	$F_p = \frac{P}{P_s} = \cos\theta$	
F_q	Reactive factor	$F_q = \frac{P_q}{P_s} = \sin\theta$	
F_p	Power factor	$F_p = \cos\tan^{-1}\frac{P_q}{P}$	
F_q	Reactive factor	$F_q = \sin\tan^{-1}\frac{P_q}{P}$	

E_m, I_m and P_m should be used for maximum cyclic values, e, i, and p for instantaneous values, E and I for root-mean-square values, and P for the average value of power. These distinctions are not necessary in dealing with direct-current circuits. Vector quantities are preferably represented by bold face capitals.

WIRE CALCULATIONS

Ohm's Law

Ohm's Law: $I = \frac{E}{R}$ where I is current, E is voltage, and R is resistance.

Example: With a voltage of 112 and a resistance of 8 ohms, what current would flow?

$$I = \frac{112}{8} = 14 \text{ amperes.}$$

Example: What resistance is necessary to obtain a current of 14 amperes at 112 volts?

$$R = \frac{E}{I} = \frac{112}{14} = 8 \text{ ohms.}$$

Example: What voltage would be required to produce a flow of 14 amperes through a resistance of 8 ohms?

$$E = IR = 14 \times 8 = 112 \text{ volts.}$$

Voltage Drop

The resistance of a copper wire one foot long and one circular mil in cross section is 10.371 ohms at 20 C (*National Bureau of Standards*). 10.4 is used for practical calculations.

In Ohm's law $I = \frac{E}{R}$, R is equal to:

Length of conductor in feet × 10.4 divided by the sectional area in circular mils of the conductor or,

$$R = \frac{2 \times \text{feet (length of circuit)} \times 10.4}{\text{cir mil}}$$

Using Ohm's law, $E = IR$,

$$E = \frac{\text{Amp} \times 2 \times \text{feet} \times 10.4}{\text{cir mil}}$$

where the term *feet* indicates the length of the circuit, the number of feet of wire in the circuit being double the length of the circuit.

Example: What would be the volts lost in a circuit of No. 12 wire carrying 20 amperes a distance of 50 feet?

$$E = \frac{20 \times 2 \times 50 \times 10.4}{6530} = 3.18 \text{ volts}$$

drop, or approximately 3% on a 110-volt circuit.

Example: What size of conductor would be necessary to give a 3% drop on a 110 volt circuit carrying 20 amperes a distance of 50 feet?

$$\text{cir mil} = \frac{\text{Amp} \times 2 \times \text{feet} \times 10.4}{E}$$

$$\text{cir mil} = \frac{20 \times 2 \times 50 \times 10.4}{3.3} = 6303$$

cir mil or approximately a No. 12 wire.

Example: What current can a No. 12 wire carry on a 50 foot circuit with a voltage drop of 3.3 volts?

$$\text{Amp} = \frac{\text{cir mil} \times E}{2 \times \text{feet} \times 10.4} =$$

$$I = \frac{6530 \times 3.3}{50 \times 2 \times 10.4} \text{ or } 20.7 \text{ amperes.}$$

TABLE 18-E

ALLOWABLE NUMBER OF WIRES IN CONDUIT

Rubber Covered, Types RF-32, R, RH, RW and RU
Thermoplastic, Types TF, T and TW

Size AWG MCM	Number of Conductors in One Conduit or Tubing								
	1	2	3	4	5	6	7	8	9
18	½	½	½	½	½	½	½	¾	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	1	1	1
12	½	½	½	¾	¾	1	1	1	1¼
10	½	¾	¾	¾	1	1	1	1¼	1¼
8	½	¾	¾	1	1¼	1¼	1¼	1½	1½
6	½	1	1	1¼	1½	1½	2	2	2
4	½	1¼	1¼	1½	1½	2	2	2	2½
3	¾	1¼	1¼	1½	2	2	2	2½	2½
2	¾	1¼	1¼	2	2	2	2½	2½	2½
1	¾	1½	1½	2	2½	2½	2½	3	3
0	1	1½	2	2	2½	2½	3	3	3
00	1	2	2	2½	2½	3	3	3	3½
000	1	2	2	2½	3	3	3	3½	3½
0000	1¼	2	2½	3	3	3	3½	3½	4
250	1¼	2½	2½	3	3	3½	4	4	4½
300	1¼	2½	2½	3	3½	4	4	4½	4½
350	1¼	3	3	3½	3½	4	4½	4½	5
400	1½	3	3	3½	4	4	4½	5	5
500	1½	3	3	3½	4	4½	5	5	6
600	2	3½	3½	4	4½	5	6	6	6
700	2	3½	3½	4½	5	5	6	6	. . .
750	2	3½	3½	4½	5	6	6	6	. . .
800	2	3½	4	4½	5	6	6	. . .	. . .
900	2	4	4	5	6	6	6	. . .	. . .
1,000	2	4	4	5	6	6	. . .	. . .	. . .
1,250	2½	4½	4½	6	6	. . .	. . .	. . .	. . .
1,500	3	5	5	6	. . .	. . .	. . .	. . .	. . .
1,750	3	5	6	6	. . .	. . .	. . .	. . .	. . .
2,000	3	6	6	. . .	. . .	. . .	. . .	. . .	. . .

Note.—The above data is taken from the *National Electrical Code* 1947 edition. Latest editions should always be consulted, as the values may be revised.

For lead covered conductors, combinations of conductors, for more than nine conductors in conduit or tubing, and for complete details of the application of the data in the table, see *National Electrical Code*, chapter 10.

TABLE 18-F

ALLOWABLE CURRENT-CARRYING CAPACITIES OF CONDUCTORS IN AMPERES

Not More Than Three Conductors in Raceway or Cable
(Based on Room Temperature of 30 C, 86 F)

Size AWG MCM	Area Cir Mils	Rubber Type R Type RW Type RU (14-6)	Rubber Type RH	D. C. Resistance Ohms/M Ft At 25 C, 77 F	
		Thermoplastic Type T (14—4/0) Type TW (14—4/0)		Bare Cond.	
14	4107	15	15	2.575	
12	6530	20	20	1.619	
10	10380	30	30	1.018	
8	16510	40	45	.641	
6	26250	55	65	.410	
4	41740	70	85	.259	
3	52640	80	100	.205	
2	66370	95	115	.162	
1	83690	110	130	.129	
0	105500	125	150	.102	
00	133100	145	175	.0811	
000	167800	165	200	.0642	
0000	211600	195	230	.0509	
250	250000	215	255	.0431	
300	300000	240	285	.0360	
350	350000	260	310	.0308	
400	400000	280	335	.0270	
500	500000	320	380	.0216	
600	600000	355	420	.0180	
700	700000	385	460	.0154	
750	750000	400	475	.0144	
800	800000	410	490	.0135	
900	900000	435	520	.0120	
1,000	1000000	455	545	.0108	
1,250	1250000	495	590	.00864	
1,500	1500000	520	625	.00719	
1,750	1750000	545	650	.00617	
2,000	2000000	560	665	.00539	

Note.—These tables are safe carrying capacity only. Voltage drop must be calculated.

The above data is taken from the *National Electrical Code* 1947 edition. Latest editions should always be consulted, as the values may be revised.

For other types of insulation, for bare conductors, for correction factors for room temperatures above 30 C (86 F) and for complete details of the application of the data in the table, see *National Electrical Code*, chapter 10.

For aluminum conductors, the allowable current carrying capacities shall be taken as 84 per cent of those given in the table for the respective sizes of copper conductor with the same kind of insulation.

TABLE 18-G

FUSING CURRENTS OF COPPER, GERMAN SILVER OR IRON WIRES

B. & S. Gage	Copper Amperes	German Silver Amperes	Iron Amperes	B. & S. Gage	Copper Amperes	German Silver Amperes	Iron Amperes
10	333	169	101	26	20.6	10.6	6.22
11	284	146	86	27	17.7	9.1	5.36
12	235	120.7	71.2	28	14.7	7.5	4.45
13	200	102.6	63	29	12.5	6.41	3.79
14	166	85.2	50.2	30	10.25	5.26	3.11
15	139	71.2	42.1	31	8.75	4.49	2.65
16	117	60.0	35.5	32	7.26	3.73	2.2
17	99	50.4	32.6	33	6.19	3.18	1.88
18	82.8	42.5	25.1	34	5.12	2.64	1.55
19	66.7	34.2	20.2	35	4.37	2.24	1.33
20	58.3	29.9	17.7	36	3.62	1.86	1.09
21	49.3	25.3	14.9	37	3.08	1.58	.93
22	41.2	21.1	12.5	38	2.55	1.31	.77
23	34.5	17.7	10.9	39	2.20	1.13	.67
24	28.9	14.8	8.76	40	1.86	.95	.56
25	24.6	12.6	7.46				

TABLE 18-H

TABULAR COMPARISON OF WIRE GAGES

Gage No.	American Wire Gage (B. & S.) Exact Sizes	American Wire Gage (B. & S.) Commercial Sizes	Steel Wire Gage (Wash. & Moen)	Birmingham Wire Gage (Stubs')	(British) Standard Wire Gage	Old English Wire Gage (London)	Stubs' Steel Wire Gage	French Gage	U. S. Standard Sheet Gage	Gage No.
7–0	.....	....	490.0	....	500.0	....	....	...	500.00	7–0
6–0	.....	....	461.5	....	464.0	....	....	...	468.7	6–0
5–0	.....	....	430.5	....	432.0	....	....	...	437.5	5–0
4–0	460.00	460.0	393.8	454.0	400.0	454.0	....	...	406.2	4–0
3–0	409.64	410.0	362.5	425.0	372.0	425.0	....	...	375.0	3–0
2–0	364.80	365.0	331.0	380.0	348.0	380.0	....	...	343.7	2–0
0	324.86	325.0	306.5	340.0	324.0	340.0	....	...	312.5	0
1	289.30	289.9	283.0	300.0	300.0	300.0	227.0	33.0	281.2	1
2	257.63	258.0	262.5	284.0	276.0	284.0	219.0	40.0	265.6	2
3	229.42	229.0	243.7	259.0	252.0	259.0	212.0	50.0	250.0	3
4	204.31	204.0	225.3	238.0	232.0	238.0	207.0	63.0	234.4	4
5	181.94	182.0	207.0	220.0	212.0	220.0	204.0	68.0	218.7	5
6	162.02	162.0	192.0	203.0	192.0	203.0	201.0	83.0	203.5	6
7	144.29	144.0	177.0	180.0	176.0	180.0	199.0	97.0	187.5	7
8	128.49	128.0	162.0	165.0	160.0	165.0	197.0	110.0	171.9	8
9	114.42	114.0	148.3	148.0	144.0	148.0	194.0	120.0	156.2	9
10	101.90	102.0	135.0	134.0	128.0	134.0	191.0	135.0	140.6	10
11	90.74	91.0	120.5	120.0	116.0	120.0	188.0	149.0	125.0	11
12	80.81	81.0	105.5	109.0	104.0	109.0	185.0	162.0	109.4	12
13	71.96	72.0	91.5	95.0	92.0	95.0	182.0	172.0	93.7	13
14	64.08	64.0	80.0	83.0	80.0	83.0	180.0	185.0	78.1	14
15	57.07	57.0	72.0	72.0	72.0	72.0	178.0	197.0	70.3	15
16	50.82	51.0	62.5	65.0	64.0	65.0	175.0	212.0	62.5	16
17	45.26	45.0	54.0	58.0	56.0	58.0	172.0	225.0	56.2	17
18	40.30	40.0	47.5	49.0	48.0	49.0	168.0	238.0	50.0	18
19	35.89	36.0	41.0	42.0	40.0	40.0	164.0	250.0	43.7	19
20	31.96	32.0	34.8	35.0	36.0	35.0	161.0	263.0	37.5	20
21	28.46	28.5	31.7	32.0	32.0	31.5	157.0	279.0	34.4	21
22	25.35	25.3	28.6	28.0	28.0	29.5	155.0	290.0	31.2	22
23	22.57	22.6	25.8	25.0	24.0	27.0	153.0	303.0	28.1	23
24	20.10	20.1	23.0	22.0	22.0	25.0	151.0	316.0	25.0	24
25	17.90	17.9	20.4	20.0	20.0	23.0	148.0	331.0	21.9	25
26	15.94	15.9	18.1	18.0	18.0	20.5	146.0	342.0	18.7	26
27	14.20	14.2	17.3	16.0	16.4	18.75	143.0	356.0	17.2	27
28	12.64	12.6	16.2	14.0	14.8	16.50	139.0	371.0	15.6	28
29	11.26	11.3	15.0	13.0	13.6	15.50	134.0	383.0	14.1	29
30	10.03	10.0	14.0	12.0	12.4	13.75	127.0	394.0	12.5	30
31	8.928	8.9	13.2	10.0	11.6	12.25	120.0	408.0	10.9	31
32	7.950	8.0	12.8	9.0	10.8	11.25	115.0	419.0	10.1	32
33	7.080	7.1	11.8	8.0	10.0	10.25	112.0	431.0	9.4	33
34	6.305	6.3	10.4	7.0	9.2	9.50	110.0	448.0	8.6	34
35	5.615	5.6	9.5	5.0	8.4	9.00	108.0	458.0	7.8	35
36	5.000	5.0	9.0	4.0	7.6	7.50	106.0	472.0	7.0	36
37	4.453	4.5	8.5	....	6.8	6.50	103.0	485.0	6.6	37
38	3.965	4.0	8.0	....	6.0	5.75	101.0	499.0	6.2	38
39	3.531	3.5	7.5	....	5.2	5.00	99.0	509.0	....	39
40	3.145	3.1	7.0	....	4.8	4.50	97.0	524.0	....	40
41	.....	....	6.6	....	4.4	....	95.0	....	....	41
42	.....	....	6.2	....	4.0	....	92.0	....	....	42
43	.....	....	6.0	....	3.6	....	88.0	....	....	43
44	.....	....	5.8	....	3.2	....	85.0	....	....	44
45	.....	....	5.5	....	2.8	....	81.0	....	....	45
46	.....	....	5.2	....	2.4	....	79.0	....	....	46
47	.....	....	5.0	....	2.0	....	77.0	....	....	47
48	.....	....	4.8	....	1.6	....	75.0	....	....	48
49	.....	....	4.6	....	1.2	....	72.0	....	....	49
50	.....	....	4.4	....	1.0	....	69.0	....	....	50

See Bureau of Standards Circular No. 67, "Wire Gages," for a combined table of sizes in the principal wire gages.

TABLE 18-I

AMPERE RATINGS OF A-C AND D-C MOTORS AT FULL LOAD

The following table gives average current values for motors of various types. Variations of 10 per cent above or below the values given may be expected. The table is based on the *National Electrical Code* 1947.

HP	110 Volts		115 Volts	220 Volts			230 Volts		440 Volts			550 Volts			2300 Volts	
	A-C Induction		D-C	A-C Induction			D-C	A-C Induction				D-C	A-C Induction		A-C Induction	
	Phase			Phase				Phase					Phase		Phase	
	2	3		1	2	3		1*	1	2	3		2	3	2	3
1/6				3.2				1.6								
1/4				4.6				2.3								
1/2	4	4	4.6	7.4	2	2	2.3	3.7		1	1		0.8	0.8		
3/4	4.8	5.6	6.6	10.2	2.4	2.8	3.3	5.1		1.2	1.4	1.4	1.0	1.1		
1	6.4	7	8.6	13	3.2	3.5	4.3	6.5		1.6	1.8	1.8	1.3	1.4		
1½	8.8	10	12.6	18.4	4.4	5	6.3	9.2		2.2	2.5	2.6	1.8	2.0		
2	11.2	13	16.4	24	5.6	6.5	8.2	12		2.8	3.3	3.4	2.2	2.6		
3			24	34	8	9	12	17		4	4.5	5.0	3.2	4		
5			40	56	13	15	20	28		7	7.5	8.3	6	6		
7½			58	80	19	22	29	40	21	9	11	12	8	9		
10			76	100	24	27	38	50	26	12	14	16	10	11		
15			112		34	40	56			17	20	23	14	16		
20			148		45	52	74			23	26	31	18	21		
25			184		55	64	92			28	32	38	22	26	6	7
30			220		67	78	110			34	39	46	27	31	7.5	8.5
40			292		88	104	146			44	52	61	35	41	9	10.5
50			360		108	125	180			54	63	75	43	50	11	13
60			430		129	150	215			65	75	90	52	60	13	16
75			536		158	185	268			79	93	111	63	74	16	19
100					212	246	355			106	123	148	85	98	21	25
125					268	310	443			134	155	184	108	124	26	31
150					311	360	534			155	180	220	124	144	31	37
200					415	480	712			208	240	295	166	192	41	49
Synchronous Motors (at unity power factor)																
25					47	54				24	27		19	22	4.7	5.4
30					56	65				29	33		23	26	5.7	6.5
40					75	86				37	43		31	35	7	8
50					94	108				47	54		38	44	9	10
60					111	128				56	64		44	51	11	12
75					140	161				70	81		57	65	13	15
100					182	211				93	106		74	85	17	20
125					228	264				114	132		93	106	22	25
150										137	158		110	127	26	30
200										182	210		145	168	35	40

These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the nameplate current rating should be used.

* For full-load currents of 208- and 200-volt motors, increase corresponding 230-volt motor full-load current by 10 and 15 per cent respectively.

CURRENT CALCULATIONS

The formula $W = EI$, where $W =$ watts; $E =$ voltage; and $I =$ current, can be used to determine the watts, $W = EI$; the voltage, $E = \frac{W}{I}$; or the current, $I = \frac{W}{E}$. This formula is applicable where the power-factor is unity. To determine the current:

2-Wire, Direct Current: $I = \frac{W}{E}$.

3-Wire, Direct Current: $I = \frac{W}{2E}$

where E is the voltage between the outside wire and the neutral.

2-Wire, Single-Phase: $I = \frac{W}{E \times F}$

where F represents the power factor of the circuit.

3-Wire, Single-Phase: $I = \frac{W}{2E \times F}$

TABLE 18-J

USEFUL ELECTRICAL FORMULAS

FOR DETERMINING AMPERES, HORSEPOWER, KILOWATTS AND KILOVOLT AMPERES

To find	Direct-current	Alternating Current		
		Single-phase	Two-phase* Four-wire	Three-phase
Amperes when horsepower is known	$\frac{746\,Hp}{E\,\eta}$	$\frac{746\,Hp}{E\,F\,\eta}$	$\frac{746\,Hp}{2\,E\,F\,\eta}$	$\frac{746\,Hp}{1.73\,E\,F\,\eta}$
Amperes when kilowatts is known	$\frac{1000\,P}{E}$	$\frac{1000\,P}{E\,F}$	$\frac{1000\,P}{2\,E\,F}$	$\frac{1000\,P}{1.73\,E\,F}$
Amperes when kva is known		$\frac{1000\,P_s}{E}$	$\frac{1000\,P_s}{2\,E}$	$\frac{1000\,P_s}{1.73\,E}$
Kilowatts	$\frac{EI}{1000}$	$\frac{EI\,F}{1000}$	$\frac{2\,EI\,F}{1000}$	$\frac{1.73\,EI\,F}{1000}$
Kilovolt-amperes		$\frac{EI}{1000}$	$\frac{2\,EI}{1000}$	$\frac{1.73\,EI}{1000}$
Horsepower (output)	$\frac{EI\,\eta}{746}$	$\frac{EI\,F\,\eta}{746}$	$\frac{2\,EI\,F\,\eta}{746}$	$\frac{1.73\,EI\,F\,\eta}{746}$

I = Amperes; E = Volts; η = per cent efficiency; F = Power factor; P = Kilowatts; P_s = Kilovolt-amperes; Hp = Horsepower.

* For three-wire, two-phase circuits the current in the common conductor is 1.41 times that in either of the other two conductors.

TABLE 18-K

GEAR TABLE—DIAMETRAL PITCH (Nuttal)

Diametral Pitch is the Number of Teeth to Each Inch of the Pitch Diameter

To Find	Having	Rule
The Diametral Pitch...	The Circular Pitch	Divide 3.1416 by the Circular Pitch.
The Diametral Pitch...	The Pitch Diameter and the Number of Teeth	Divide Number of Teeth by Pitch Diameter.
The Diametral Pitch...	The Outside Diameter and the Number of Teeth	Divide Number of Teeth plus 2 by Outside Diameter.
Pitch Diameter........	The Number of Teeth and the Diametral Pitch	Divide Number of Teeth by the Diametral Pitch.
Pitch Diameter........	The Number of Teeth and Outside Diameter	Divide the product of Outside Diameter and Number of Teeth by Number of Teeth plus 2.
Pitch Diameter........	The Outside Diameter and the Diametral Pitch	Subtract from Outside Diameter the quotient of 2 divided by the Diametral Pitch.
Pitch Diameter........	Addendum and the Number of Teeth	Multiply Addendum by the Number of Teeth.
Outside Diameter......	The Number of Teeth and the Diametral Pitch	Divide the Number of Teeth plus 2 by the Diametral Pitch.
Outside Diameter......	The Pitch Diameter and the Diametral Pitch	Add to the Pitch Diameter the quotient of 2 divided by the Diametral Pitch.
Outside Diameter......	The Pitch Diameter and the Number of Teeth	Divide Product of Number of Teeth plus 2 and Pitch Diameter by the Number of Teeth.
Outside Diameter......	The Number of Teeth and Addendum	Multiply the Number of Teeth plus 2 by Addendum.
Number of Teeth......	The Pitch Diameter and the Diametral Pitch	Multiply Pitch Diameter by the Diametral Pitch.
Number of Teeth......	The Outside Diameter and the Diametral Pitch	Multiply Outside Diameter by the Diametral Pitch and subtract 2.
Thickness of Tooth.....	The Diametral Pitch	Divide 1.5708 by the Diametral Pitch.
Addendum...........	The Diametral Pitch	Divide 1 by the Diametral Pitch, or $s = \frac{D'}{N}$.
Root.................	The Diametral Pitch	Divide 1.157 by the Diametral Pitch.
Working Depth........	The Diametral Pitch	Divide 2 by the Diametral Pitch.
Whole Depth..........	The Diametral Pitch	Divide 2.157 by the Diametral Pitch.
Clearance.............	The Diametral Pitch	Divide .157 by the Diametral Pitch.
Clearance.............	Thickness of Tooth	Divide Thickness of Tooth at pitch line by 10.

where E is the voltage between the outside wire and the neutral.

3-Wire, Three-Phase:

$I = \frac{W}{1.73\,E \times F}$ where E is the voltage between outside wires.

4-Wire, Three-Phase Y:

$I = \frac{W}{3\,E \times F}$ where E is the voltage between the outside wire and the neutral.

DATA ON PULLEYS AND GEARS

For single decrease or increase of rpm by means of belting where the rpm at which each shaft should run is known, and one pulley is in place; multiply the diameter of the pulley in place by the number of revolutions per minute that its shaft makes; divide this product by the speed in rpm at which the second shaft should run. The result is the diameter of pulley to use.

Where both shafts with pulleys are in operation and the speed of one is known; multiply rpm of shaft by diameter of its pulley and divide this product by diameter of pulley on the other shaft. The result is the rpm of the second shaft.

Where a counter shaft is used, to obtain size of main driving or driven pulley, or speed of main driving or driven shaft, it is necessary to calculate, as above, between the known end of the transmission and the countershaft, then repeat this calculation between the countershaft and the unknown end.

The rpm of each of two intermeshing gears are inversely proportional to the number of teeth on the gears. Count the number of teeth in the gear wheel and use this quantity instead of the diameter of pulley, mentioned above, to obtain number of teeth cut in unknown gear or speed of second shaft.

The above information may be expressed algebraically as follows:

Rule for Finding Size of Pulleys

$$d = \frac{D \times S}{S'} \qquad D = \frac{d \times S'}{S}$$

d = diameter of driven pulley, or number of teeth on driven gear.
D = diameter of driving pulley, or number of teeth on driving gear.
S = number of revolutions per minute of driving pulley, or driving gear.
S' = number of revolutions per minute of driven pulley, or driven gear.

TRIGONOMETRIC FUNCTIONS

In the solution of alternating-current problems requiring the use of trigonometric functions, the following tabulation of their definitions and interrelations will be useful.

In the right triangle ABC, the ratios between the lengths of sides of the triangle determine the trigonometric functions of the angle A as follows:

$$\sin A = \frac{1}{\csc A} = \frac{\cos A}{\cot A}$$

$$\cos A = \frac{1}{\sec A} = \frac{\sin A}{\tan A}$$

$$\tan A = \frac{1}{\cot A} = \frac{\sin A}{\cos A}$$

$$\cot A = \frac{1}{\tan A} = \frac{\cos A}{\sin A}$$

$$\sec A = \frac{1}{\cos A} = \frac{\tan A}{\sin A}$$

$$\csc A = \frac{1}{\sin A} = \frac{\cot A}{\cos A}$$

For example, the sine of A is the ratio of "a" to "c", or the ratio of the side opposite the angle A to the hypotenuse (side opposite the right angle). The cosine of A is the ratio of "b" to "c", or the ratio of the side adjacent to the angle A to the hypotenuse, etc.

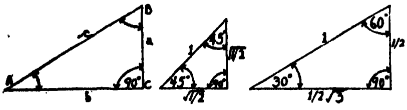

Fig. 18-1. Functions of a Right Triangle

While $\frac{a}{c}$ is the sine of A, it is also the cosine of B since side "a" is adjacent to angle B. Therefore it will be seen that—

$$\begin{array}{l|l} \sin A = \cos B & \cot A = \tan B \\ \cos A = \sin B & \sec A = \csc B \\ \tan A = \cot B & \csc A = \sec B \end{array}$$

Numerical values for the functions of every angle are computed from the ratios of the sides of a right triangle containing that angle. In a right triangle, which is a triangle containing one right (90°) angle, the sum of the other two angles must equal 90°, since the sum of the three angles of any triangle must be 180°. Also the sum of the squares of the two shorter sides must equal the square of the longer side or hypotenuse (the side opposite the 90° angle). Regardless of the values which may be assigned to the sides of a right triangle, the ratio of any two sides for any given angle is always the same.

$\sin 30° = \cos 60° =$

$$\frac{\frac{1}{2}}{1} = \frac{1}{2} = 0.500$$

$\cos 30° = \sin 60° =$

$$\frac{\frac{1}{2}\sqrt{3}}{1} = \frac{1}{2}\sqrt{3} = 0.866$$

$\tan 30° = \cot 60° =$

$$\frac{\frac{1}{2}}{\frac{1}{2}\sqrt{3}} = \frac{1}{\sqrt{3}} = 0.577$$

$\sin 45° = \cos 45° =$

$$\frac{\sqrt{\frac{1}{2}}}{1} = \sqrt{\frac{1}{2}} = 0.707$$

$\tan 45° = \cot 45° =$

$$\frac{\sqrt{\frac{1}{2}}}{\sqrt{\frac{1}{2}}} = 1 = 1.000$$

TABLE 18-L

SIGNS OF THE FUNCTIONS OF ANGLES

	sin cos	tan cot	sec csc
1st Quadrant (0° to 90°)	+ +	+ +	+ +
2d Quadrant (90° to 180°)	+ −	− −	− +
3d Quadrant (180° to 270°)	− −	+ +	− −
4th Quadrant (270° to 360°)	− +	− −	+ −

TABLE 18-M
VALUES OF COMMONLY USED TRIGONOMETRIC FUNCTIONS

Angle	Sin	Cos	Tan	Cot	Sec	Csc
0	0.000	1.000	0.000	∞	1.000	∞
15	0.259	0.966	0.268	3.732	1.035	3.861
30	$0.500 = \left(\frac{1}{2}\right)$	$0.866 = \left(\frac{\sqrt{3}}{2}\right)$	$0.577 = \left(\frac{1}{\sqrt{3}}\right)$	$1.732 = \left(\sqrt{3}\right)$	$1.155 = \left(\frac{2}{\sqrt{3}}\right)$	2.000
45	$0.707 = \left(\frac{1}{\sqrt{2}}\right)$	$0.707 = \left(\frac{1}{\sqrt{2}}\right)$	1.000	1.000	$1.414 = \left(\sqrt{2}\right)$	$1.414 = \left(\sqrt{2}\right)$
60	$0.866 = \left(\frac{\sqrt{3}}{2}\right)$	$0.500 = \left(\frac{1}{2}\right)$	$1.732 = \left(\sqrt{3}\right)$	$0.577 = \left(\frac{1}{\sqrt{3}}\right)$	2.000	$1.155 = \left(\frac{2}{\sqrt{3}}\right)$
75	0.966	0.259	3.732	0.268	3.861	1.035
90	1.000	0.000	∞	0.000	∞	1.000
120	$0.866 = \left(\frac{\sqrt{3}}{2}\right)$	$-0.500 = \left(-\frac{1}{2}\right)$	$-1.732 = \left(-\sqrt{3}\right)$	$-0.577 = \left(-\frac{1}{\sqrt{3}}\right)$	-2.000	$1.155 = \left(\frac{2}{\sqrt{3}}\right)$
150	$0.500 = \left(\frac{1}{2}\right)$	$-0.866 = \left(-\frac{\sqrt{3}}{2}\right)$	$-0.577 = \left(-\frac{1}{\sqrt{3}}\right)$	$-1.732 = \left(-\sqrt{3}\right)$	$-1.155 = \left(-\frac{2}{\sqrt{3}}\right)$	2.000
180	0.000	-1.000	0.000	∞	-1.000	∞
270	-1.000	0.000	∞	0.000	∞	-1.000
360	0.000	1.000	0.000	∞	1.000	∞

∞ = infinity

Electrical problems occasionally require the use of the following formulae giving functions of the sum or difference of two angles:

$$\sin(x \pm y) = \sin x \cos y \pm \cos x \sin y$$
$$\cos(x \pm y) = \cos x \cos y \mp \sin x \sin y$$

To determine the functions of an angle greater than 90° and less than 180°, subtract the angle from 180° and refer to the table of functions. For an angle greater than 180° and less than 270°, subtract 180° from the angle and refer to table. For an angle greater than 270° and less than 360°, subtract the angle from 360° and refer to table.

The algebraic signs of the functions of all angles between 0° and 90° are +, beyond 90° the signs may be determined from Table 18-L.

When an angle becomes slightly greater than 360° it again falls into the first quadrant, and its trigonometric values are those of the angle minus 360°.

Table 18-M shows the numerical values of the functions of the angles most generally encountered in the study of electrical problems, while Table 18-N gives the values for all angles.

THE SLIDE RULE

General Description—The slide rule consists of a stock or body grooved lengthwise to carry a slide. On the face of the rule are engraved four (or more) scales known as the A, B, C and D scales. The A and B scales are on the stock and slide respectively and are adjacent to the upper edge of the groove. The C and D scales are on the slide and stock adjacent to the lower edge of the groove. All four scales are so divided that the distance from the first mark at the left to any point on the scale is proportional to the logarithm of the number shown on the scale. Scales A and B cover the range from 1 to 10 in half the length of the rule. Scales C and D are expanded so that the range 1 to 10 covers the whole rule. These latter scales are therefore used for the simpler problems on account of the ease and accuracy with which they may be read.

Scales A and B have three indexes each. The extreme left-hand end is numbered 1 and is known as the *left index;* the middle is also numbered 1 and is known as the *middle index;* the extreme right-hand end is also numbered 1 and is known as the *right index.* Scales C and D have only the left index and right index at the ends of the scales. It will be noted that the next major line beyond 9 is in all cases numbered 1 instead of 10. The computations are carried through without consideration for the decimal point as

TABLE 18-N

NATURAL TRIGONOMETRIC FUNCTIONS

FOUR-PLACE VALUES OF TRIGONOMETRIC FUNCTIONS

°	′	N. Sin.	N. Tan.	N. Cot.	N. Cos.		
0	00	0.0000	0.0000	∞	1.0000	00	90
	10	.0029	.0029	343.77	1.0000	50	
	20	.0058	.0058	171.89	1.0000	40	
	30	.0087	.0087	114.59	1.0000	30	
	40	.0116	.0116	85.940	.9999	20	
	50	.0145	.0145	68.750	.9999	10	
1	00	.0175	.0175	57.290	.9998	00	89
	10	.0204	.0204	49.104	.9998	50	
	20	.0233	.0233	42.964	.9997	40	
	30	.0262	.0262	38.188	.9997	30	
	40	.0291	.0291	34.368	.9996	20	
	50	.0320	.0320	31.242	.9995	10	
2	00	.0349	.0349	28.636	.9994	00	88
	10	.0378	.0378	26.432	.9993	50	
	20	.0407	.0407	24.542	.9992	40	
	30	.0436	.0437	22.904	.9990	30	
	40	.0465	.0466	21.470	.9989	20	
	50	.0494	.0495	20.206	.9988	10	
3	00	.0523	.0524	19.081	.9986	00	87
	10	.0552	.0553	18.075	.9985	50	
	20	.0581	.0582	17.169	.9983	40	
	30	.0610	.0612	16.350	.9981	30	
	40	.0640	.0641	15.605	.9980	20	
	50	.0669	.0670	14.924	.9978	10	
4	00	.0698	.0699	14.301	.9976	00	86
	10	.0727	.0729	13.727	.9974	50	
	20	.0756	.0758	13.197	.9971	40	
	30	.0785	.0787	12.706	.9969	30	
	40	.0814	.0816	12.251	.9967	20	
	50	.0843	.0846	11.826	.9964	10	
5	00	.0872	.0875	11.430	.9962	00	85
	10	.0901	.0904	11.059	.9959	50	
	20	.0929	.0934	10.712	.9957	40	
	30	.0958	.0963	10.385	.9954	30	
	40	.0987	.0992	10.078	.9951	20	
	50	.1016	.1022	9.7882	.9948	10	
6	00	.1045	.1051	9.5144	.9945	00	84
	10	.1074	.1080	9.2553	.9942	50	
	20	.1103	.1110	9.0098	.9939	40	
	30	.1132	.1139	8.7769	.9936	30	
	40	.1161	.1169	8.5555	.9932	20	
	50	.1190	.1198	8.3450	.9929	10	
7	00	.1219	.1228	8.1443	.9925	00	83
	10	.1248	.1257	7.9530	.9922	50	
	20	.1276	.1287	7.7704	.9918	40	
	30	.1305	.1317	7.5958	.9914	30	
	40	.1334	.1346	7.4287	.9911	20	
	50	.1363	.1376	7.2687	.9907	10	
8	00	.1392	.1405	7.1154	.9903	00	82
	10	.1421	.1435	6.9682	.9899	50	
	20	.1449	.1465	6.8269	.9894	40	
	30	.1478	.1495	6.6912	.9890	30	
	40	.1507	.1524	6.5606	.9886	20	
	50	.1536	.1554	6.4348	.9881	10	
9	00	.1564	.1584	6.3138	.9877	00	81
	10	.1593	.1614	6.1970	.9872	50	
	20	.1622	.1644	6.0844	.9868	40	
	30	.1650	.1673	5.9758	.9863	30	
	40	.1679	.1703	5.8708	.9858	20	
	50	.1708	.1733	5.7694	.9853	10	
10	00	.1736	.1763	5.6713	.9848	00	80
	10	.1765	.1793	5.5764	.9843	50	
	20	.1794	.1823	5.4845	.9838	40	
	30	.1822	.1853	5.3955	.9833	30	
	40	.1851	.1883	5.3093	.9827	20	
	50	.1880	.1914	5.2257	.9822	10	
11	00	0.1908	0.1944	5.1446	0.9816	00	79
	10	.1937	.1974	5.0658	.9811	50	
	20	.1965	.2004	4.9894	.9805	40	
	30	.1994	.2035	4.9152	.9799	30	
	40	.2022	.2065	4.8430	.9793	20	
	50	.2051	.2095	4.7729	.9787	10	
12	00	.2079	.2126	4.7046	.9781	00	78
	10	.2108	.2156	4.6382	.9775	50	
	20	.2136	.2186	4.5736	.9769	40	
	30	.2164	.2217	4.5107	.9763	30	
	40	.2193	.2247	4.4494	.9757	20	
	50	.2221	.2278	4.3897	.9750	10	
13	00	.2250	.2309	4.3315	.9744	00	77
	10	.2278	.2339	4.2747	.9737	50	
	20	.2306	.2370	4.2193	.9730	40	
	30	.2334	.2401	4.1653	.9724	30	
	40	.2363	.2432	4.1126	.9717	20	
	50	.2391	.2462	4.0611	.9710	10	
14	00	.2419	.2493	4.0108	.9703	00	76
	10	.2447	.2524	3.9617	.9696	50	
	20	.2476	.2555	3.9136	.9689	40	
	30	.2504	.2586	3.8667	.9681	30	
	40	.2532	.2617	3.8208	.9674	20	
	50	.2560	.2648	3.7760	.9667	10	
15	00	.2588	.2679	3.7321	.9659	00	75
	10	.2616	.2711	3.6891	.9652	50	
	20	.2644	.2742	3.6470	.9644	40	
	30	.2672	.2773	3.6059	.9636	30	
	40	.2700	.2805	3.5656	.9628	20	
	50	.2728	.2836	3.5261	.9621	10	
16	00	.2756	.2867	3.4874	.9613	00	74
	10	.2784	.2899	3.4495	.9605	50	
	20	.2812	.2931	3.4124	.9596	40	
	30	.2840	.2962	3.3759	.9588	30	
	40	.2868	.2994	3.3402	.9580	20	
	50	.2896	.3026	3.3052	.9572	10	
17	00	.2924	.3057	3.2709	.9563	00	73
	10	.2952	.3089	3.2371	.9555	50	
	20	.2979	.3121	3.2041	.9546	40	
	30	.3007	.3153	3.1716	.9537	30	
	40	.3035	.3185	3.1397	.9528	20	
	50	.3062	.3217	3.1084	.9520	10	
18	00	.3090	.3249	3.0777	.9511	00	72
	10	.3118	.3281	3.0475	.9502	50	
	20	.3145	.3314	3.0178	.9492	40	
	30	.3173	.3346	2.9887	.9483	30	
	40	.3201	.3378	2.9600	.9474	20	
	50	.3228	.3411	2.9319	.9465	10	
19	00	.3256	.3443	2.9042	.9455	00	71
	10	.3283	.3476	2.8770	.9446	50	
	20	.3311	.3508	2.8502	.9436	40	
	30	.3338	.3541	2.8239	.9426	30	
	40	.3365	.3574	2.7980	.9417	20	
	50	.3393	.3607	2.7725	.9407	10	
20	00	.3420	.3640	2.7475	.9397	00	70
	10	.3448	.3673	2.7228	.9387	50	
	20	.3475	.3706	2.6985	.9377	40	
	30	.3502	.3739	2.6746	.9367	30	
	40	.3529	.3772	2.6511	.9356	20	
	50	.3557	.3805	2.6279	.9346	10	
21	00	.3584	.3839	2.6051	.9336	00	69
	10	.3611	.3872	2.5826	.9325	50	
	20	.3638	.3906	2.5605	.9315	40	
	30	.3665	.3939	2.5386	.9304	30	
	40	.3692	.3973	2.5172	.9293	20	
	50	.3719	.4006	2.4960	.9283	10	
		N. Cos.	N. Cot.	N. Tan.	N. Sin.	′	°

TABLE 18-N—(Continued) Natural Trigonometric Functions

°	′	N. Sin.	N. Tan.	N. Cot.	N. Cos.		
22	00	0.3746	0.4040	2.4751	0.9272	00	**68**
	10	.3773	.4074	2.4545	.9261	50	
	20	.3800	.4108	2.4342	.9250	40	
	30	.3827	.4142	2.4142	.9239	30	
	40	.3854	.4176	2.3945	.9228	20	
	50	.3881	.4210	2.3750	.9216	10	
23	00	.3907	.4245	2.3559	.9205	00	**67**
	10	.3934	.4279	2.3369	.9194	50	
	20	.3961	.4314	2.3183	.9182	40	
	30	.3987	.4348	2.2998	.9171	30	
	40	.4014	.4383	2.2817	.9159	20	
	50	.4041	.4417	2.2637	.9147	10	
24	00	.4067	.4452	2.2460	.9135	00	**66**
	10	.4094	.4487	2.2286	.9124	50	
	20	.4120	.4522	2.2113	.9112	40	
	30	.4147	.4557	2.1943	.9100	30	
	40	.4173	.4592	2.1775	.9088	20	
	50	.4200	.4628	2.1609	.9075	10	
25	00	.4226	.4663	2.1445	.9063	00	**65**
	10	.4253	.4699	2.1283	.9051	50	
	20	.4279	.4734	2.1123	.9038	40	
	30	.4305	.4770	2.0965	.9026	30	
	40	.4331	.4806	2.0809	.9013	20	
	50	.4358	.4841	2.0655	.9001	10	
26	00	.4384	.4877	2.0503	.8988	00	**64**
	10	.4410	.4913	2.0353	.8975	50	
	20	.4436	.4950	2.0204	.8962	40	
	30	.4462	.4986	2.0057	.8949	30	
	40	.4488	.5022	1.9912	.8936	20	
	50	.4514	.5059	1.9768	.8923	10	
27	00	.4540	.5095	1.9626	.8910	00	**63**
	10	.4566	.5132	1.9486	.8897	50	
	20	.4592	.5169	1.9347	.8884	40	
	30	.4617	.5206	1.9210	.8870	30	
	40	.4643	.5243	1.9074	.8857	20	
	50	.4669	.5280	1.8940	.8843	10	
28	00	.4695	.5317	1.8807	.8829	00	**62**
	10	.4720	.5354	1.8676	.8816	50	
	20	.4746	.5392	1.8546	.8802	40	
	30	.4772	.5430	1.8418	.8788	30	
	40	.4797	.5467	1.8291	.8774	20	
	50	.4823	.5505	1.8165	.8760	10	
29	00	.4848	.5543	1.8040	.8746	00	**61**
	10	.4874	.5581	1.7917	.8732	50	
	20	.4899	.5619	1.7796	.8718	40	
	30	.4924	.5658	1.7675	.8704	30	
	40	.4950	.5696	1.7556	.8689	20	
	50	.4975	.5735	1.7437	.8675	10	
30	00	.5000	.5774	1.7321	.8660	00	**60**
	10	.5025	.5812	1.7205	.8646	50	
	20	.5050	.5851	1.7090	.8631	40	
	30	.5075	.5890	1.6977	.8616	30	
	40	.5100	.5930	1.6864	.8601	20	
	50	.5125	.5969	1.6753	.8587	10	
31	00	.5150	.6009	1.6643	.8572	00	**59**
	10	.5175	.6048	1.6534	.8557	50	
	20	.5200	.6088	1.6426	.8542	40	
	30	.5225	.6128	1.6319	.8526	30	
	40	.5250	.6168	1.6212	.8511	20	
	50	.5275	.6208	1.6107	.8496	10	
32	00	.5299	.6249	1.6003	.8480	00	**58**
	10	.5324	.6289	1.5900	.8465	50	
	20	.5348	.6330	1.5798	.8450	40	
	30	.5373	.6371	1.5697	.8434	30	
	40	.5398	.6412	1.5597	.8418	20	
	50	.5422	.6453	1.5497	.8403	10	
33	00	.5446	.6494	1.5399	.8387	00	**57**
	10	.5471	.6536	1.5301	.8371	50	
	20	.5495	.6577	1.5204	.8355	40	
	30	.5519	.6619	1.5108	.8339	30	
	40	.5544	.6661	1.5013	.8323	20	
	50	.5568	.6703	1.4919	.8307	10	
34	00	0.5592	0.6745	1.4826	0.8290	00	**56**
	10	.5616	.6787	1.4733	.8274	50	
	20	.5640	.6830	1.4641	.8258	40	
	30	.5664	.6873	1.4550	.8241	30	
	40	.5688	.6916	1.4460	.8225	20	
	50	.5712	.6959	1.4370	.8208	10	
35	00	.5736	.7002	1.4281	.8192	00	**55**
	10	.5760	.7046	1.4193	.8175	50	
	20	.5783	.7089	1.4106	.8158	40	
	30	.5807	.7133	1.4019	.8141	30	
	40	.5831	.7177	1.3934	.8124	20	
	50	.5854	.7221	1.3848	.8107	10	
36	00	.5878	.7265	1.3764	.8090	00	**54**
	10	.5901	.7310	1.3680	.8073	50	
	20	.5925	.7355	1.3597	.8056	40	
	30	.5948	.7400	1.3514	.8039	30	
	40	.5972	.7445	1.3432	.8021	20	
	50	.5995	.7490	1.3351	.8004	10	
37	00	.6018	.7536	1.3270	.7986	00	**53**
	10	.6041	.7581	1.3190	.7969	50	
	20	.6065	.7627	1.3111	.7951	40	
	30	.6088	.7673	1.3032	.7934	30	
	40	.6111	.7720	1.2954	.7916	20	
	50	.6134	.7766	1.2876	.7898	10	
38	00	.6157	.7813	1.2799	.7880	00	**52**
	10	.6180	.7860	1.2723	.7862	50	
	20	.6202	.7907	1.2647	.7844	40	
	30	.6225	.7954	1.2572	.7826	30	
	40	.6248	.8002	1.2497	.7808	20	
	50	.6271	.8050	1.2423	.7790	10	
39	00	.6293	.8098	1.2349	.7771	00	**51**
	10	.6316	.8146	1.2276	.7753	50	
	20	.6338	.8195	1.2203	.7735	40	
	30	.6361	.8243	1.2131	.7716	30	
	40	.6383	.8292	1.2059	.7698	20	
	50	.6406	.8342	1.1988	.7679	10	
40	00	.6428	.8391	1.1918	.7660	00	**50**
	10	.6450	.8441	1.1847	.7642	50	
	20	.6472	.8491	1.1778	.7623	40	
	30	.6494	.8541	1.1708	.7604	30	
	40	.6517	.8591	1.1640	.7585	20	
	50	.6539	.8642	1.1571	.7566	10	
41	00	.6561	.8693	1.1504	.7547	00	**49**
	10	.6583	.8744	1.1436	.7528	50	
	20	.6604	.8796	1.1369	.7509	40	
	30	.6626	.8847	1.1308	.7490	30	
	40	.6648	.8899	1.1237	.7470	20	
	50	6670	.8952	1.1171	.7451	10	
42	00	.6691	.9004	1.1106	.7431	00	**48**
	10	.6713	.9057	1.1041	.7412	50	
	20	.6734	.9110	1.0977	.7392	40	
	30	.6756	.9163	1.0913	.7373	30	
	40	.6777	.9217	1.0850	.7353	20	
	50	.6799	.9271	1.0786	.7333	10	
43	00	.6820	.9325	1.0724	.7314	00	**47**
	10	.6841	.9380	1.0661	.7294	50	
	20	.6862	.9435	1.0599	.7274	40	
	30	.6884	.9490	1.0538	.7254	30	
	40	.6905	.9545	1.0477	.7234	20	
	50	.6926	.9601	1.0416	.7214	10	
44	00	.6947	.9657	1.0355	.7193	00	**46**
	10	.6967	.9713	1.0295	.7173	50	
	20	.6988	.9770	1.0235	.7153	40	
	30	.7009	.9827	1.0176	.7133	30	
	40	.7030	.9884	1.0117	.7112	20	
	50	.7050	.9942	1.0058	.7092	10	
45	00	.7071	1.0000	1.0000	.7071	00	**45**
		N. Cos.	N. Cot.	N. Tan.	N. Sin.	′	°

far as locations on the rule are concerned.

The numbers on the scales can be assumed as 1, 2, 3, etc.; 10, 20, 30, etc.; 0.1, 0.2, 0.3, etc.; or any decimal or multiple thereof. The settings for 0.25, 2.5, 25, 250, etc., are at the same points on the scales. The position of the decimal point can be found by inspection in the majority of all computations in meter testing.

A runner of glass or celluloid slides across the whole face of the rule. It is usually engraved with a single hair line, crossing all four scales perpendicularly, and is used to mark positions pending further setting of the slide, and to facilitate reading the result.

The slide rule in its 10-inch size may be depended upon for three digits or decimal places. If the computation involves only the left part of the lower scales, up to 2, four digits or places may be read. These accuracies are not usually exceeded. The error in calculations over the whole or the lower scales may be regarded as not greater than one tenth of one per cent. The rule, however, while not an instrument of precision, is sufficiently accurate for the purposes of meter computations.

The operation of the rule consists in adding or subtracting the distances between engraved marks on the scales, such marks corresponding to the numerical values stated in the problem to be solved.

The addition of such distances gives the product of the numbers.

The subtraction of such distances gives the quotient of the numbers.

Simple addition or subtraction cannot be performed on the slide rule.

Higher functions such as roots, squares, cubes, etc., may be handled, but their use in general is outside the needs of the meter tester.

Proportion—A fundamental property of the slide rule is that, with any position of the slide, all numbers on the slide bear equal proportions to their coinciding numbers on the rule. For example, if we place the left index (1) on the C scale over 2 on D, we find as follows:

C—1, 2, 3, 4, 4.5
D—2, 4, 6, 8, 9, etc.

Inspection will show that the ratio of a number on C to its coinciding number on D is a constant over the whole scale.

To solve a proportion then requires the operator to set the rule in the following manner:

Over the second term of the proportion on Scale D, set the first term on Scale C, and under the third term on Scale C, read the fourth term on Scale D, which is the answer sought. In doing this use the runner to mark the exact position of the number on Scale D to insure that the desired number on Scale C is over the exact number on Scale D. In like manner, use slide to locate the other two numbers.

For brevity and clearness, the operations set forth in the last paragraph are shown graphically below. It will be noted that the center line represents the division between the two scales which are marked. The first section represents the first operation and the second section the second operation. If a third section is used, it represents the third operation, etc.

C	set 1st term	under 3rd term
D	over 2nd term	read 4th term

This method will be used throughout this discussion in showing the sequence of operations in the solution of problems.

Example No. 1.—A non-inductive resistance carries 3 amps, when the impressed voltage is 20. What current will it carry at 50 volts?

Solution:

$$20 : 50 = 3 : X \quad (1)$$

C	set 20	under 3
D	over 50	read 7.5

7.5 amp is the answer sought.

Multiplication—Since the slide rule is scaled in distances proportional to the logarithms of numbers, and since to multiply numbers we add their logarithms, it follows that to perform multiplication on the rule we must add distances. To multiply 3 by 2,

C	set 1 (left index)	under 2
D	Over 3	read 6 (product)

i.e., over 3 (the multiplicand) on Scale D, set the left index of Scale C. Under 2 (the multiplier) on Scale C read 6 (the product) on Scale D. To locate more easily the number on Scale D, use the runner, placing the hair line on the number on Scale C. We have added the distance 1 to 3 to the distance 1 to 2 and obtained the distance 1 to 6.

When multiplying more than two factors, use the runner to mark a subproduct temporarily while making a second movement of the slide. When a number to be set lies beyond the end of the rule on the slide, or beyond the end of the slide on the rule, set the runner on the index of the slide, and move the slide its whole length, setting the other index under the hair line of the runner. The number can then be set or read.

Example No. 2.—To find the power in a circuit of 110 volts, 4.5 amp., 80% power factor, or

$$4.5 \times 110 \times 0.80 = 396 \text{ watts.} \qquad (2)$$

C	set 1 (left)	set runner on 4.5
D	over 110	

C	set 1 on runner (right)	under 0.80
D		read 396 watts

396 watts is the answer sought.

Division—To perform the division of one number by another, we must subtract the logarithm of the divisor from the logarithm of the dividend. To divide 6 by 2,

C	set 2	under 1 (left)
D	over 6	read 3 (quotient)

This will be seen to be the reverse process to that shown for multiplication of 3 by 2. Use the runner to locate 6 definitely and to be sure that 2 is set directly over 6. This is useful especially when one or both numbers do not fall on even divisions.

Example No. 3.—To find the power factor of a circuit of 110 volts, 4.5 amps., and 396 watts, or

$$396 \div 110 \div 4.5 = 0.80 \text{ or } 80\% \text{ power factor.} \qquad (3)$$

C	set 110	set runner to 1 (left)
D	over 396	

C	set 4.5 to runner	under 1 (right)
D		read 0.80 power factor

80% power factor is the result sought.

Where the numerator and the denominator are approximately of the same magnitude, accuracy of calculation can be considerably increased by subtracting one from the other and dividing out the remainder. For example,

$\frac{127}{125}$ is equal to $1 + \frac{2}{125}$. Use the slide rule to determine $\frac{2}{125}$ and then add 1 to the result. In like manner, $\frac{125}{127}$ equals $1 - \frac{2}{127}$.

Squares and Square Roots—All operations so far described have been confined to the C and D scales. The relation between Scale A (or B) and D (or C) is such that any number on D (or C) is directly beneath the square of that number on A (or B). Conversely, any number on A (or B) is directly over the square root of that number on D (or C). In this case it should be remembered that the square roots of 3 and 30 differ by more than a decimal point. Numbers on Scale A must be considered as running from 1 up to 10 at the middle index and from 10 on to 100 at the right index. Placing runner on 2 on Scale D gives 4 on Scale A which is the square of 2. Placing runner on 3 on Scale A at left of middle index gives 1.732+ on scale D which is the square root of 3. Setting on 3 on Scale A at the right of the middle index gives 5.477+ which is the square root of 30.

Application to Meter Testing

Example No. 4.—Referring to Section 9, under *Indicating Instrument Method* of testing watthour meters, we find the following equation:

Percentage registration =

$$\frac{k_h \times r \times 3600 \times 100}{P \times s}$$

Assume a 5-amp, 110-volt, 25-cycle, I-14 meter tested at full load, giving the following values: $k_h = 0.3$, $r = 20$, $s = 43$, $P = 500$. The equation then becomes

Percentage Registration =

$$\frac{0.3 \times 20 \times 3600 \times 100}{500 \times 43} = 100.5. \quad (4)$$

Its solution is as follows:

C	set 1 (left)	runner to 20	1 to runner (right)	runner to 3600
D	over 3			

C	500 to runner	runner to 1 (right)	43 to runner	under 1 (left)
D				read 1005

The operation may be simplified however by performing the divisions and multiplications alternately as follows:

C	set 500	runner to 20	43 to runner	under 3600
D	over 3			read 1005

Inspection of the numerical equation (4) above to locate the decimal point would be somewhat after this manner: 3600 ÷ 43 = about 100; 100 × 0.3 × 20 = 600; 600 ÷ 500 = about 1; 1 × 100 = 100. Therefore the result of the slide rule computation will be approximately 100. Hence 100.5% is the answer.

Example No. 5.—Referring to Section 9, under *Portable Standard Watthour Meter Method* of testing watthour meters; we find the following equation:

$$\begin{array}{l}\text{Percentage}\\ \text{registration}\end{array} = \frac{k_h \times r}{K_h \times R} \times 100.$$

Assume a 15-amp, 110-volt, 25-cycle, I-14 meter at full load tested by an IB-5, 20-amp, 110-volt portable standard watthour meter, giving the following values: $k_h = 0.9$, $r = 20$, $K_h = 1.2$, $R = 15.20$. The equation then becomes:

Percentage registration =

$$\frac{0.9 \times 20}{1.2 \times 15.2} \times 100 = 98.7\% \quad (5)$$

and its solution becomes

C	Set 1.2	runner to 1 (left)	15.20 to runner	under 20
D	over 0.9			read 987

By inspection for decimal point: 0.9 × 20 = about 20; 20 ÷ 1.2 = about 15; 15 ÷ 15.2 = about 1; 1 × 100 = 100. Therefore 98.7% is the answer.

Example No. 6.—Again using the equation under Example No. 5 above, assume the same meter tested at light load by an IB-5 portable standard watthour meter with 1-amp coil, giving the following values: $k_h = 0.9$, $r = 1$, $K_h = 0.06$, $R = 29$. The equation then becomes:

$$\text{Percentage registration} = \frac{0.9 \times 1}{0.06 \times 29} \times 100 = 51.7\% \qquad (6)$$

and the computation becomes:

C	set 0.06	runner to 1 (left)	29 to runner	under 1 (right)
D	over 0.9			read 517

By inspection for decimal point: 0.9×1 = about 1; $1 \div 0.06$ = about 15; $15 \div 29$ = about ½; ½ × 100 = 50. Therefore 51.7% is the answer.

If the results of the above kind of problems are desired in per cent error, a little practice will enable the tester to perform the usual "percentage registration − 100 = % error" on the slide rule. In problem No. 1 above where the result is near the left index, it will be noted that each division on Scale D is worth 1%. Therefore the % error can be read directly in this case as +0.5%.

In Example No. 5, where the result is near the right index, each smallest division is worth ½ of 1%, and each next larger division 1%. The % error can therefore be read by counting divisions and fractions from the right and using the minus sign. Example No. 5 then gives −1.3% error.

In Example No. 6, the same method applies, counting right to left gives the solution as −48.3% error.

Calculations of Ratios Near Unity—In the calculation of ratios near unity the slide rule may not be sufficiently accurate for direct use. Methods are available, however, by means of which the slide rule may be used to determine such ratios with greater accuracy.

The determination of meter registration may be taken as representative

$$\text{Registration} = \frac{\text{meter watts } (A)}{\text{true watts } (B)}$$

In this case the application of a 10-inch slide rule gives an accuracy of reading of about 0.1%.

Where $A > B$

$$\text{Registration} = 1 + \left(\frac{A - B}{B}\right)$$

As an example in the above formula, if $A = 1239$ watts and $B = 1200$ watts, their difference $(A - B)$ equals 39 and $\frac{39}{1200}$ is 0.0325 by slide rule. Adding 1 the registration is 1.0325.

Using the slide rule directly $\frac{A}{B} = \frac{1239}{1200}$ = 1.033 approximately.

If $A < B$

$$\text{Registration} = 1 - \left(\frac{B - A}{B}\right)$$

If in this case $A = 1413$ watts and B is 1450 watts, their difference $(B - A)$ is 37, and $\frac{37}{1450}$ is 0.0255 by slide rule. Subtracting from 1, the registration of the meter is 0.9745

By slide rule direct

$$\frac{A}{B} = \frac{1413}{1450} = 0.974 \text{ approximately.}$$

Multiplication of Quantities Near Unity—If two quantities which are near unity are to be multiplied, the accuracy obtainable by the use of a slide rule may be improved by the method given below.

To multiply 1.0044 by 0.9944, the result by using the slide rule directly is 0.999 (approximately).

For a more accurate result: Separate one of the quantities into two parts, one of which is 1.

1.0044 then becomes (1 + 0.0044)
or 0.9944 becomes (1 − 0.0056)

Using the separation of the first quantity (1 + 0.0044), multiply each part separately by the other quantity.

0.9944 × 1 = 0.9944
0.9944 × 0.0044 (by slide rule) = 0.00437
Adding, the result = 0.99877

as compared to 0.999 by the direct method.

If the separation of the second quantity (1 − 0.0056) is used, the values become

1.0044 × 1 = 1.0044
1.0044 × −0.0056 = −0.00563
Adding, the result = 0.99877

Practice Problems

It is suggested that the following problems be solved by means of the slide rule in accordance with the foregoing instructions. Proficiency in the use of the slide rule depends to a great extent upon experience. The problems given will serve to assist in attaining the skill which is necessary for the rapid and accurate use of the slide rule.

1. 12 × 35 × 15 = 6300.
2. 1.25 × 37.5 ÷ 2 = 23.4+.
3. 332 ÷ 1230 ÷ 9 = 0.03.
4. 224 : 915 = 93 : X. X = 379.9.
5. 499 ÷ 501 = 0.996+.
6. 1025 ÷ 9.96 = 102.9+.
7. 11.11 × 900 = 10,000.
8. Find the power in a direct-current circuit of 112 volts and 16 ohms. Ans. 784 watts.

TABLE 18-O

COMMON LOGARITHMS OF NUMBERS

100-199

N	O	1	2	3	4	5	6	7	8	9	D	N	O	1	2	3	4	5	6	7	8	9	D
100	00 000	043	087	130	173	217	260	303	346	389	43	150	609	638	667	696	725	754	782	811	840	869	29
101	432	475	518	561	604	647	689	732	775	817	43	151	898	926	955	984	*013	*041	*070	*099	*127	*156	29
102	860	903	945	988	*030	*072	*115	*157	*199	*242	42	152	18 184	213	241	270	298	327	355	384	412	441	29
103	01 284	326	368	410	452	494	536	578	620	662	42	153	469	498	526	554	583	611	639	667	696	724	28
104	703	745	787	828	870	912	953	995	*036	*078	42	154	752	780	808	837	865	893	921	949	977	*005	28
105	02 119	160	202	243	284	325	366	407	449	490	41	155	19 033	061	089	117	145	173	201	229	257	285	28
106	531	572	612	653	694	735	776	816	857	898	41	156	312	340	368	396	424	451	479	507	535	562	28
107	938	979	*019	*060	*100	*141	*181	*222	*262	*302	40	157	590	618	645	673	700	728	756	783	811	838	28
108	03 342	383	423	463	503	543	583	623	663	703	40	158	866	893	921	948	976	*003	*030	*058	*085	*112	27
109	743	782	822	862	902	941	981	*021	*060	*100	40	159	20 140	167	194	222	249	276	303	330	358	385	27
110	04 139	179	218	258	297	336	376	415	454	493	39	160	412	439	466	493	520	548	575	602	629	656	27
111	532	571	610	650	689	727	766	805	844	883	39	161	683	710	737	763	790	817	844	871	898	925	27
112	922	961	999	*038	*077	*115	*154	*192	*231	*269	39	162	952	978	*005	*032	*059	*085	*112	*139	*165	*192	27
113	05 308	346	385	423	461	500	538	576	614	652	38	163	21 219	245	272	299	325	352	378	405	431	458	27
114	690	729	767	805	843	881	918	956	994	*032	38	164	484	511	537	564	590	617	643	669	696	722	26
115	06 070	108	145	183	221	258	296	333	371	408	38	165	748	775	801	827	854	880	906	932	958	985	26
116	446	483	521	558	595	633	670	707	744	781	37	166	22 011	037	063	089	115	141	167	194	220	246	26
117	819	856	893	930	967	*004	*041	*078	*115	*151	37	167	272	298	324	350	376	401	427	453	479	505	26
118	07 188	225	262	298	335	372	408	445	482	518	37	168	531	557	583	608	634	660	686	712	737	763	26
119	555	591	628	664	700	737	773	809	846	882	36	169	789	814	840	866	891	917	943	968	994	*019	26
120	918	954	990	*027	*063	*099	*135	*171	*207	*243	36	170	23 045	070	096	121	147	172	198	223	249	274	25
121	08 279	314	350	386	422	458	493	529	565	600	36	171	300	325	350	376	401	426	452	477	502	528	25
122	636	672	707	743	778	814	849	884	920	955	35	172	553	578	603	629	654	679	704	729	754	779	25
123	991	*026	*061	*096	*132	*167	*202	*237	*272	*307	35	173	805	830	855	880	905	930	955	980	*005	*030	25
124	09 342	377	412	447	482	517	552	587	621	656	35	174	24 055	080	105	130	155	180	204	229	254	279	25
125	691	726	760	795	830	864	899	934	968	*003	35	175	304	329	353	378	403	428	452	477	502	527	25
126	10 037	072	106	140	175	209	243	278	312	346	34	176	551	576	601	625	650	674	699	724	748	773	25
127	380	415	449	483	517	551	585	619	653	687	34	177	797	822	846	871	895	920	944	969	993	*018	25
128	721	755	789	823	857	890	924	958	992	*025	34	178	25 042	066	091	115	139	164	188	212	237	261	24
129	11 059	093	126	160	193	227	261	294	327	361	34	179	285	310	334	358	382	406	431	455	479	503	24
130	394	428	461	494	528	561	594	628	661	694	33	180	527	551	575	600	624	648	672	696	720	744	24
131	727	760	793	826	860	893	926	959	992	*024	33	181	768	792	816	840	864	888	912	935	959	983	24
132	12 057	090	123	156	189	222	254	287	320	352	33	182	26 007	031	055	079	102	126	150	174	198	221	24
133	385	418	450	483	516	548	581	613	646	678	33	183	245	269	293	316	340	364	387	411	435	458	24
134	710	743	775	808	840	872	905	937	969	*001	32	184	482	505	529	553	576	600	623	647	670	694	24
135	13 033	066	098	130	162	194	226	258	290	322	32	185	717	741	764	788	811	834	858	881	905	928	23
136	354	386	418	450	481	513	545	577	609	640	32	186	951	975	998	*021	*045	*068	*091	*114	*138	*161	23
137	672	704	735	767	799	830	862	893	925	956	32	187	27 184	207	231	254	277	300	323	346	370	393	23
138	988	*019	*051	*082	*114	*145	*176	*208	*239	*270	31	188	416	439	462	485	508	531	554	577	600	623	23
139	14 301	333	364	395	426	457	489	520	551	582	31	189	646	669	692	715	738	761	784	807	830	852	23
140	613	644	675	706	737	768	799	829	860	891	31	190	875	898	921	944	967	989	*012	*035	*058	*081	23
141	922	953	983	*014	*045	*076	*106	*137	*168	*198	31	191	28 103	126	149	171	194	217	240	262	285	307	23
142	15 229	259	290	320	351	381	412	442	473	503	31	192	330	353	375	398	421	443	466	488	511	533	23
143	534	564	594	625	655	685	715	746	776	806	30	193	556	578	601	623	646	668	691	713	735	758	22
144	836	866	897	927	957	987	*017	*047	*077	*107	30	194	780	803	825	847	870	892	914	937	959	981	22
145	16 137	167	197	227	256	286	316	346	376	406	30	195	29 003	026	048	070	092	115	137	159	181	203	22
146	435	465	495	524	554	584	613	643	673	702	30	196	226	248	270	292	314	336	358	380	403	425	22
147	732	761	791	820	850	879	909	938	967	997	29	197	447	469	491	513	535	557	579	601	623	645	22
148	17 026	056	085	114	143	173	202	231	260	289	29	198	667	688	710	732	754	776	798	820	842	863	22
149	319	348	377	406	435	464	493	522	551	580	29	199	885	907	929	951	973	994	*016	*035	*060	*081	22

PROPORTIONAL PARTS.

PP	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22
1	4.4	4.3	4.2	4.1	4.0	3.9	3.8	3.7	3.6	3.5	3.4	3.3	3.2	3.1	3.0	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2
2	8.8	8.6	8.4	8.2	8.0	7.8	7.6	7.4	7.2	7.0	6.8	6.6	6.4	6.2	6.0	5.8	5.6	5.4	5.2	5.0	4.8	4.6	4.4
3	13.2	12.9	12.6	12.3	12.0	11.7	11.4	11.1	10.8	10.5	10.2	9.9	9.6	9.3	9.0	8.7	8.4	8.1	7.8	7.5	7.2	6.9	6.6
4	17.6	17.2	16.8	16.4	16.0	15.6	15.2	14.8	14.4	14.0	13.6	13.2	12.8	12.4	12.0	11.6	11.2	10.8	10.4	10.0	9.6	9.2	8.8
5	22.0	21.5	21.0	20.5	20.0	19.5	19.0	18.5	18.0	17.5	17.0	16.5	16.0	15.5	15.0	14.5	14.0	13.5	13.0	12.5	12.0	11.5	11.0
6	26.4	25.8	25.2	24.6	24.0	23.4	22.8	22.2	21.6	21.0	20.4	19.8	19.2	18.6	18.0	17.4	16.8	16.2	15.6	15.0	14.4	13.8	13.2
7	30.8	30.1	29.4	28.7	28.0	27.3	26.6	25.9	25.2	24.5	23.8	23.1	22.4	21.7	21.0	20.3	19.6	18.9	18.2	17.5	16.8	16.1	15.4
8	35.2	34.4	33.6	32.8	32.0	31.2	30.4	29.6	28.8	28.0	27.2	26.4	25.6	24.8	24.0	23.2	22.4	21.6	20.8	20.0	19.2	18.4	17.6
9	39.6	38.7	37.8	36.9	36.0	35.1	34.2	33.3	32.4	31.5	30.6	29.7	28.8	27.9	27.0	26.1	25.2	24.3	23.4	22.5	21.6	20.7	19.8

*Use next highest number, as indicated in column "O," for the first two digits.

TABLE 18-O (Continued)—Common Logarithms of Numbers

200-369

N	O	1	2	3	4	5	6	7	8	9	D
200	30 103	125	146	168	190	211	233	255	276	298	22
201	320	341	363	384	406	428	449	471	492	514	22
202	535	557	578	600	621	643	664	685	707	728	21
203	750	771	792	814	835	856	878	899	920	942	21
204	963	984	*006	*027	*048	*069	*091	*112	*133	*154	21
205	31 175	197	218	239	260	281	302	323	345	366	21
206	387	408	429	450	471	492	513	534	555	576	21
207	597	618	639	660	681	702	723	744	765	785	21
208	806	827	848	869	890	911	931	952	973	994	21
209	32 015	035	056	077	098	118	139	160	181	201	21
210	222	243	263	284	305	325	346	366	387	408	21
211	428	449	469	490	510	531	552	572	593	613	20
212	634	654	675	695	715	736	756	777	797	818	20
213	838	858	879	899	919	940	960	980	*001	*021	20
214	33 041	062	082	102	122	143	163	183	203	224	20
215	244	264	284	304	325	345	365	385	405	425	20
216	445	465	486	506	526	546	566	586	606	626	20
217	646	666	686	706	726	746	766	786	806	826	20
218	846	866	885	905	925	945	965	985	*005	*025	20
219	34 044	064	084	104	124	143	163	183	203	223	20
220	242	262	282	301	321	341	361	380	400	420	20
221	439	459	479	498	518	537	557	577	596	616	19
222	635	655	674	694	713	733	753	772	792	811	19
223	830	850	869	889	908	928	947	967	986	*005	19
224	35 025	044	064	083	102	122	141	160	180	199	19
225	218	238	257	276	295	315	334	353	372	392	19
226	411	430	449	468	488	507	526	545	564	583	19
227	603	622	641	660	679	698	717	736	755	774	19
228	793	813	832	851	870	889	908	927	946	965	19
229	984	*003	*021	*040	*059	*078	*097	*116	*135	*154	19
230	36 173	192	211	229	248	267	286	305	324	342	19
231	361	380	399	418	436	455	474	493	511	530	19
232	549	568	586	605	624	642	661	680	698	717	19
233	736	754	773	791	810	829	847	866	884	903	19
234	922	940	959	977	996	*014	*033	*051	*070	*088	18
235	37 107	125	144	162	181	199	218	236	254	273	18
236	291	310	328	346	365	383	401	420	438	457	18
237	475	493	511	530	548	566	585	603	621	639	18
238	658	676	694	712	731	749	767	785	803	822	18
239	840	858	876	894	912	931	949	967	985	*003	18
240	38 021	039	057	075	093	112	130	148	166	184	18
241	202	220	238	256	274	292	310	328	346	364	18
242	382	399	417	435	453	471	489	507	525	543	18
243	561	578	596	614	632	650	668	686	703	721	18
244	739	757	775	792	810	828	846	863	881	899	18
245	917	934	952	970	987	*005	*023	*041	*058	*076	18
246	39 094	111	129	146	164	182	199	217	235	252	18
247	270	287	305	322	340	358	375	393	410	428	18
248	445	463	480	498	515	533	550	568	585	602	18
249	620	637	655	672	690	707	724	742	759	777	17
250	794	811	829	846	863	881	898	915	933	950	17
251	967	985	*002	*019	*037	*054	*071	*088	*106	*123	17
252	40 140	157	175	192	209	226	243	261	278	295	17
253	312	329	346	364	381	398	415	432	449	466	17
254	483	500	518	535	552	569	586	603	620	637	17
255	654	671	688	705	722	739	756	773	790	807	17
256	824	841	858	875	892	909	926	943	960	976	17
257	993	*010	*027	*044	*061	*078	*095	*111	*128	*145	17
258	41 162	179	196	212	229	246	263	280	296	313	17
259	330	347	363	380	397	414	430	447	464	481	17
260	497	514	531	547	564	581	597	614	631	647	17
261	664	681	697	714	731	747	764	780	797	814	17
262	830	847	863	880	896	913	929	946	963	979	16
263	996	*012	*029	*045	*062	*078	*095	*111	*127	*144	16
264	42 160	177	193	210	226	243	259	275	292	308	16
265	325	341	357	374	390	406	423	439	455	472	16
266	488	504	521	537	553	570	586	602	619	635	16
267	651	667	684	700	716	732	749	765	781	797	16
268	813	830	846	862	878	894	911	927	943	959	16
269	975	991	*008	*024	*040	*056	*072	*088	*104	*120	16
270	43 136	152	169	185	201	217	233	249	265	281	16
271	297	313	329	345	361	377	393	409	425	441	16
272	457	473	489	505	521	537	553	569	584	600	16
273	616	632	648	664	680	696	712	727	743	759	16
274	775	791	807	823	838	854	870	886	902	917	16
275	933	949	965	981	996	*012	*028	*044	*059	*075	16
276	44 091	107	122	138	154	170	185	201	217	232	16
277	248	264	279	295	311	326	342	358	373	389	16
278	404	420	436	451	467	483	498	514	529	545	16
279	560	576	592	607	623	638	654	669	685	700	16
280	716	731	747	762	778	793	809	824	840	855	15
281	871	886	902	917	932	948	963	979	994	*010	15
282	45 025	040	056	071	086	102	117	133	148	163	15
283	179	194	209	225	240	255	271	286	301	317	15
284	332	347	362	378	393	408	423	439	454	469	15
285	484	500	515	530	545	561	576	591	606	621	15
286	637	652	667	682	697	712	728	743	758	773	15
287	788	803	818	834	849	864	879	894	909	924	15
288	939	954	969	984	*000	*015	*030	*045	*060	*075	15
289	46 090	105	120	135	150	165	180	195	210	225	15
290	240	255	270	285	300	315	330	345	359	374	15
291	389	404	419	434	449	464	479	494	509	523	15
292	538	553	568	583	598	613	627	642	657	672	15
293	687	702	716	731	746	761	776	790	805	820	15
294	835	850	864	879	894	909	923	938	953	967	15
295	982	997	*012	*026	*041	*056	*070	*085	*100	*114	15
296	47 129	144	159	173	188	202	217	232	246	261	15
297	276	290	305	319	334	349	363	378	392	407	15
298	422	436	451	465	480	494	509	524	538	553	15
299	567	582	596	611	625	640	654	669	683	698	15
300	712	727	741	756	770	784	799	813	828	842	14
301	857	871	885	900	914	929	943	958	972	986	14
302	48 001	015	029	044	058	073	087	101	116	130	14
303	144	159	173	187	202	216	230	244	259	273	14
304	287	302	316	330	344	359	373	387	401	416	14
305	430	444	458	473	487	501	515	530	544	558	14
306	572	586	601	615	629	643	657	671	686	700	14
307	714	728	742	756	770	785	799	813	827	841	14
308	855	869	883	897	911	926	940	954	968	982	14
309	996	*010	*024	*038	*052	*066	*080	*094	*108	*122	14
310	49 136	150	164	178	192	206	220	234	248	262	14
311	276	290	304	318	332	346	360	374	388	402	14
312	415	429	443	457	471	485	499	513	527	541	14
313	554	568	582	596	610	624	638	651	665	679	14
314	693	707	721	734	748	762	776	790	803	817	14
315	831	845	859	872	886	900	914	927	941	955	14
316	969	982	996	*010	*024	*037	*051	*065	*079	*092	14
317	50 106	120	133	147	161	174	188	202	215	229	14
318	243	256	270	284	297	311	325	338	352	365	14
319	379	393	406	420	433	447	461	474	488	501	14
320	515	529	542	556	569	583	596	610	623	637	14
321	651	664	678	691	705	718	732	745	759	772	14
322	786	799	813	826	840	853	866	880	893	907	13
323	920	934	947	961	974	987	*001	*014	*028	*041	13
324	51 055	068	081	095	108	121	135	148	162	175	13
325	188	202	215	228	242	255	268	282	295	308	13
326	322	335	348	362	375	388	402	415	428	441	13
327	455	468	481	495	508	521	534	548	561	574	13
328	587	601	614	627	640	654	667	680	693	706	13
329	720	733	746	759	772	786	799	812	825	838	13
330	851	865	878	891	904	917	930	943	957	970	13
331	983	996	*009	*022	*035	*048	*061	*075	*088	*101	13
332	52 114	127	140	153	166	179	192	205	218	231	13
333	244	257	270	284	297	310	323	336	349	362	13
334	375	388	401	414	427	440	453	466	479	492	13
335	504	517	530	543	556	569	582	595	608	621	13
336	634	647	660	673	686	699	711	724	737	750	13
337	763	776	789	802	815	827	840	853	866	879	13
338	892	905	917	930	943	956	969	982	994	*007	13
339	53 020	033	046	058	071	084	097	110	122	135	13
340	148	161	173	186	199	212	224	237	250	263	13
341	275	288	301	314	326	339	352	364	377	390	13
342	403	415	428	441	453	466	479	491	504	517	13
343	529	542	555	567	580	593	605	618	631	643	13
344	656	668	681	694	706	719	732	744	757	769	13
345	782	794	807	820	832	845	857	870	882	895	13
346	908	920	933	945	958	970	983	995	*008	*020	13
347	54 033	045	058	070	083	095	108	120	133	145	13
348	158	170	183	195	208	220	233	245	258	270	12
349	283	295	307	320	332	345	357	370	382	394	12
350	407	419	432	444	456	469	481	494	506	518	12
351	531	543	555	568	580	593	605	617	630	642	12
352	654	667	679	691	704	716	728	741	753	765	12
353	777	790	802	814	827	839	851	864	876	888	12
354	900	913	925	937	949	962	974	986	998	*011	12
355	55 023	035	047	060	072	084	096	108	121	133	12
356	145	157	169	182	194	206	218	230	242	255	12
357	267	279	291	303	315	328	340	352	364	376	12
358	388	400	413	425	437	449	461	473	485	497	12
359	509	522	534	546	558	570	582	594	606	618	12
360	630	642	654	666	678	691	703	715	727	739	12
361	751	763	775	787	799	811	823	835	847	859	12
362	871	883	895	907	919	931	943	955	967	979	12
363	991	*003	*015	*027	*038	*050	*062	*074	*086	*098	12
364	56 110	122	134	146	158	170	182	194	205	217	12
365	229	241	253	265	277	289	301	312	324	336	12
366	348	360	372	384	396	407	419	431	443	455	12
367	467	478	490	502	514	526	538	549	561	573	12
368	585	597	608	620	632	644	656	667	679	691	12
369	703	714	726	738	750	761	773	785	797	808	12
N	O	1	2	3	4	5	6	7	8	9	D

*Use next highest number, as indicated in column "O," for the first two digits.

TABLE 18-O (Continued)—Common Logarithms of Numbers

370-539

N	O	1	2	3	4	5	6	7	8	9	D
370	820	832	844	855	867	879	891	902	914	926	12
371	937	949	961	972	984	996	*008	*019	*031	*043	12
372	57 054	066	078	089	101	113	124	136	148	159	12
373	171	183	194	206	217	229	241	252	264	276	12
374	287	299	310	322	334	345	357	368	380	392	12
375	403	415	426	438	449	461	473	484	496	507	12
376	519	530	542	553	565	576	588	600	611	623	12
377	634	646	657	669	680	692	703	715	726	738	11
378	749	761	772	784	795	807	818	830	841	852	11
379	864	875	887	898	910	921	933	944	955	967	11
380	978	990	*001	*013	*024	*035	*047	*058	*070	*081	11
381	58 092	104	115	127	138	149	161	172	184	195	11
382	206	218	229	240	252	263	274	286	297	309	11
383	320	331	343	354	365	377	388	399	410	422	11
384	433	444	456	467	478	490	501	512	524	535	11
385	546	557	569	580	591	602	614	625	636	647	11
386	659	670	681	692	704	715	726	737	749	760	11
387	771	782	794	805	816	827	838	850	861	872	11
388	883	894	906	917	928	939	950	961	973	984	11
389	995	*006	*017	*028	*040	*051	*062	*073	*084	*095	11
390	59 106	118	129	140	151	162	173	184	195	207	11
391	218	229	240	251	262	273	284	295	306	318	11
392	329	340	351	362	373	384	395	406	417	428	11
393	439	450	461	472	483	494	506	517	528	539	11
394	550	561	572	583	594	605	616	627	638	649	11
395	660	671	682	693	704	715	726	737	748	759	11
396	770	780	791	802	813	824	835	846	857	868	11
397	879	890	901	912	923	934	945	956	966	977	11
398	988	999	*010	*021	*032	*043	*054	*065	*076	*086	11
399	60 097	108	119	130	141	152	163	173	184	195	11
400	206	217	228	239	249	260	271	282	293	304	11
401	314	325	336	347	358	369	379	390	401	412	11
402	423	433	444	455	466	477	487	498	509	520	11
403	531	541	552	563	574	584	595	606	617	627	11
404	638	649	660	670	681	692	703	713	724	735	11
405	746	756	767	778	788	799	810	821	831	842	11
406	853	863	874	885	895	906	917	927	938	949	11
407	959	970	981	991	*002	*013	*023	*034	*045	*055	11
408	61 066	077	087	098	109	119	130	140	151	162	11
409	172	183	194	204	215	225	236	247	257	268	11
410	278	289	300	310	321	331	342	352	363	374	11
411	384	395	405	416	426	437	448	458	469	479	11
412	490	500	511	521	532	542	553	563	574	584	11
413	595	606	616	627	637	648	658	669	679	690	11
414	700	711	721	731	742	752	763	773	784	794	10
415	805	815	826	836	847	857	868	878	888	899	10
416	909	920	930	941	951	962	972	982	993	*003	10
417	62 014	024	034	045	055	066	076	086	097	107	10
418	118	128	138	149	159	170	180	190	201	211	10
419	221	232	242	252	263	273	284	294	304	315	10
420	325	335	346	356	366	377	387	397	408	418	10
421	428	439	449	459	469	480	490	500	511	521	10
422	531	542	552	562	572	583	593	603	613	624	10
423	634	644	655	665	675	685	696	706	716	726	10
424	737	747	757	767	778	788	798	808	818	829	10
425	839	849	859	870	880	890	900	910	921	931	10
426	941	951	961	972	982	992	*002	*012	*022	*033	10
427	63 043	053	063	073	083	094	104	114	124	134	10
428	144	155	165	175	185	195	205	215	225	236	10
429	246	256	266	276	286	296	306	317	327	337	10
430	347	357	367	377	387	397	407	417	428	438	10
431	448	458	468	478	488	498	508	518	528	538	10
432	548	558	568	579	589	599	609	619	629	639	10
433	649	659	669	679	689	699	709	719	729	739	10
434	749	759	769	779	789	799	809	819	829	839	10
435	849	859	869	879	889	899	909	919	929	939	10
436	949	959	969	979	988	998	*008	*018	*028	*038	10
437	64 048	058	068	078	088	098	108	118	128	137	10
438	147	157	167	177	187	197	207	217	227	237	10
439	246	256	266	276	286	296	306	316	326	335	10
440	345	355	365	375	385	395	404	414	424	434	10
441	444	454	464	473	483	493	503	513	523	532	10
442	542	552	562	572	582	591	601	611	621	631	10
443	640	650	660	670	680	689	699	709	719	729	10
444	738	748	758	768	777	787	797	807	816	826	10
445	836	846	856	865	875	885	895	904	914	924	10
446	933	943	953	963	972	982	992	*002	*011	*021	10
447	65 031	040	050	060	070	079	089	099	108	118	10
448	128	137	147	157	167	176	186	196	205	215	10
449	225	234	244	254	263	273	283	292	302	312	10
450	321	331	341	350	360	369	379	389	398	408	10
451	418	427	437	447	456	466	475	485	495	504	10
452	514	523	533	543	552	562	571	581	591	600	10
453	610	619	629	639	648	658	667	677	686	696	10
454	706	715	725	734	744	753	763	772	782	792	9

N	O	1	2	3	4	5	6	7	8	9	D
455	801	811	820	830	839	849	858	868	877	887	9
456	896	906	916	925	935	944	954	963	973	982	9
457	992	*001	*011	*020	*030	*039	*049	*058	*068	*077	9
458	66 087	096	106	115	124	134	143	153	162	172	9
459	181	191	200	210	219	229	238	247	257	266	9
460	276	285	295	304	314	323	332	342	351	361	9
461	370	380	389	398	408	417	427	436	445	455	9
462	464	474	483	492	502	511	521	530	539	549	9
463	558	567	577	586	596	605	614	624	633	642	9
464	652	661	671	680	689	699	708	717	727	736	9
465	745	755	764	773	783	792	801	811	820	829	9
466	839	848	857	867	876	885	894	904	913	922	9
467	932	941	950	960	969	978	987	997	*006	*015	9
468	67 025	034	043	052	062	071	080	089	099	108	9
469	117	127	136	145	154	164	173	182	191	201	9
470	210	219	228	237	247	256	265	274	284	293	9
471	302	311	321	330	339	348	357	367	376	385	9
472	394	403	413	422	431	440	449	459	468	477	9
473	486	495	504	514	523	532	541	550	560	569	9
474	578	587	596	605	614	624	633	642	651	660	9
475	669	679	688	697	706	715	724	733	742	752	9
476	761	770	779	788	797	806	815	825	834	843	9
477	852	861	870	879	888	897	906	916	925	934	9
478	943	952	961	970	979	988	997	*006	*015	*024	9
479	68 034	043	052	061	070	079	088	097	106	115	9
480	124	133	142	151	160	169	178	187	196	205	9
481	215	224	233	242	251	260	269	278	287	296	9
482	305	314	323	332	341	350	359	368	377	386	9
483	395	404	413	422	431	440	449	458	467	476	9
484	485	494	502	511	520	529	538	547	556	565	9
485	574	583	592	601	610	619	628	637	646	655	9
486	664	673	681	690	699	708	717	726	735	744	9
487	753	762	771	780	789	797	806	815	824	833	9
488	842	851	860	869	878	886	895	904	913	922	9
489	931	940	949	958	966	975	984	993	*002	*011	9
490	69 020	028	037	046	055	064	073	082	090	099	9
491	108	117	126	135	144	152	161	170	179	188	9
492	197	205	214	223	232	241	249	258	267	276	9
493	285	294	302	311	320	329	338	346	355	364	9
494	373	381	390	399	408	417	425	434	443	452	9
495	461	469	478	487	496	504	513	522	531	539	9
496	548	557	566	574	583	592	601	609	618	627	9
497	636	644	653	662	671	679	688	697	705	714	9
498	723	732	740	749	758	767	775	784	793	801	9
499	810	819	827	836	845	854	862	871	880	888	9
500	897	906	914	923	932	940	949	958	966	975	9
501	984	992	*001	*010	*018	*027	*036	*044	*053	*062	9
502	70 070	079	088	096	105	114	122	131	140	148	9
503	157	165	174	183	191	200	209	217	226	234	9
504	243	252	260	269	278	286	295	303	312	321	9
505	329	338	346	355	364	372	381	389	398	406	9
506	415	424	432	441	449	458	467	475	484	492	9
507	501	509	518	526	535	544	552	561	569	578	9
508	586	595	603	612	621	629	638	646	655	663	9
509	672	680	689	697	706	714	723	731	740	749	9
510	757	766	774	783	791	800	808	817	825	834	9
511	842	851	859	868	876	885	893	902	910	919	9
512	927	935	944	952	961	969	978	986	995	*003	9
513	71 012	020	029	037	046	054	063	071	079	088	8
514	096	105	113	122	130	139	147	155	164	172	8
515	181	189	198	206	214	223	231	240	248	257	8
516	265	273	282	290	299	307	315	324	332	341	8
517	349	357	366	374	383	391	399	408	416	425	8
518	433	441	450	458	466	475	483	492	500	508	8
519	517	525	533	542	550	559	567	575	584	592	8
520	600	609	617	625	634	642	650	659	667	675	8
521	684	692	700	709	717	725	734	742	750	759	8
522	767	775	784	792	800	809	817	825	834	842	8
523	850	858	867	875	883	892	900	908	917	925	8
524	933	941	950	958	966	975	983	991	999	*008	8
525	72 016	024	032	041	049	057	066	074	082	090	8
526	099	107	115	123	132	140	148	156	165	173	8
527	181	189	198	206	214	222	230	239	247	255	8
528	263	272	280	288	296	304	313	321	329	337	8
529	346	354	362	370	378	387	395	403	411	419	8
530	428	436	444	452	460	469	477	485	493	501	8
531	509	518	526	534	542	550	558	567	575	583	8
532	591	599	607	616	624	632	640	648	656	665	8
533	673	681	689	697	705	713	722	730	738	746	8
534	754	762	770	779	787	795	803	811	819	827	8
535	835	843	852	860	868	876	884	892	900	908	8
536	916	925	933	941	949	957	965	973	981	989	8
537	997	*006	*014	*022	*030	*038	*046	*054	*062	*070	8
538	73 078	086	094	102	111	119	127	135	143	151	8
539	159	167	175	183	191	199	207	215	223	231	8

*Use next highest number, as indicated in column "O," for the first two digits.

TABLE 18-O (Continued)—Common Logarithms of Numbers

540-709

N	O	1	2	3	4	5	6	7	8	9	D
540	239	247	255	263	272	280	288	296	304	312	8
541	320	328	336	344	352	360	368	376	384	392	8
542	400	408	416	424	432	440	448	456	464	472	8
543	480	488	496	504	512	520	528	536	544	552	8
544	560	568	576	584	592	600	608	616	624	632	8
545	640	648	656	664	672	679	687	695	703	711	8
546	719	727	735	743	751	759	767	775	783	791	8
547	799	807	815	823	830	838	846	854	862	870	8
548	878	886	894	902	910	918	926	933	941	949	8
549	957	965	973	981	989	997	*005	*013	*020	*028	8
550	74 036	044	052	060	068	076	084	092	099	107	8
551	115	123	131	139	147	155	162	170	178	186	8
552	194	202	210	218	225	233	241	249	257	265	8
553	273	280	288	296	304	312	320	327	335	343	8
554	351	359	367	374	382	390	398	406	414	421	8
555	429	437	445	453	461	468	476	484	492	500	8
556	507	515	523	531	539	547	554	562	570	578	8
557	586	593	601	609	617	624	632	640	648	656	8
558	663	671	679	687	695	702	710	718	726	733	8
559	741	749	757	764	772	780	788	796	803	811	8
560	819	827	834	842	850	858	865	873	881	889	8
561	896	904	912	920	927	935	943	950	958	966	8
562	974	981	989	997	*005	*012	*020	*028	*035	*043	8
563	75 051	059	066	074	082	089	097	105	113	120	8
564	128	136	143	151	159	166	174	182	189	197	8
565	205	213	220	228	236	243	251	259	266	274	8
566	282	289	297	305	312	320	328	335	343	351	8
567	358	366	374	381	389	397	404	412	420	427	8
568	435	442	450	458	465	473	481	488	496	504	8
569	511	519	526	534	542	549	557	565	572	580	8
570	587	595	603	610	618	626	633	641	648	656	8
571	664	671	679	686	694	702	709	717	724	732	8
572	740	747	755	762	770	778	785	793	800	808	8
573	815	823	831	838	846	853	861	868	876	884	8
574	891	899	906	914	921	929	937	944	952	959	8
575	967	974	982	989	997	*005	*012	*020	*027	*035	8
576	76 042	050	057	065	072	080	087	095	103	110	8
577	118	125	133	140	148	155	163	170	178	185	8
578	193	200	208	215	223	230	238	245	253	260	8
579	268	275	283	290	298	305	313	320	328	335	8
580	343	350	358	365	373	380	388	395	403	410	8
581	418	425	433	440	448	455	462	470	477	485	7
582	492	500	507	515	522	530	537	545	552	559	7
583	567	574	582	589	597	604	612	619	626	634	7
584	641	649	656	664	671	678	686	693	701	708	7
585	716	723	730	738	745	753	760	768	775	782	7
586	790	797	805	812	819	827	834	842	849	856	7
587	864	871	879	886	893	901	908	916	923	930	7
588	938	945	953	960	967	975	982	989	997	*004	7
589	77 012	019	026	034	041	048	056	063	070	078	7
590	085	093	100	107	115	122	129	137	144	151	7
591	159	166	173	181	188	195	203	210	217	225	7
592	232	240	247	254	262	269	276	283	291	298	7
593	305	313	320	327	335	342	349	357	364	371	7
594	379	386	393	401	408	415	422	430	437	444	7
595	452	459	466	474	481	488	495	503	510	517	7
596	525	532	539	546	554	561	568	576	583	590	7
597	597	605	612	619	627	634	641	648	656	663	7
598	670	677	685	692	699	706	714	721	728	735	7
599	743	750	757	764	772	779	786	793	801	808	7
600	815	822	830	837	844	851	859	866	873	880	7
601	887	895	902	909	916	924	931	938	945	952	7
602	960	967	974	981	988	996	*003	*010	*017	*025	7
603	78 032	039	046	053	061	068	075	082	089	097	7
604	104	111	118	125	132	140	147	154	161	168	7
605	176	183	190	197	204	211	219	226	233	240	7
606	247	254	262	269	276	283	290	297	305	312	7
607	319	326	333	340	347	355	362	369	376	383	7
608	390	398	405	412	419	426	433	440	447	455	7
609	462	469	476	483	490	497	504	512	519	526	7
610	533	540	547	554	561	569	576	583	590	597	7
611	604	611	618	625	633	640	647	654	661	668	7
612	675	682	689	696	704	711	718	725	732	739	7
613	746	753	760	767	774	781	789	796	803	810	7
614	817	824	831	838	845	852	859	866	873	880	7
615	888	895	902	909	916	923	930	937	944	951	7
616	958	965	972	979	986	993	*000	*007	*014	*021	7
617	79 029	036	043	050	057	064	071	078	085	092	7
618	099	106	113	120	127	134	141	148	155	162	7
619	169	176	183	190	197	204	211	218	225	232	7
620	239	246	253	260	267	274	281	288	295	302	7
621	309	316	323	330	337	344	351	358	365	372	7
622	379	386	393	400	407	414	421	428	435	442	7
623	449	456	463	470	477	484	491	498	505	511	7
624	518	525	532	539	546	553	560	567	574	581	7
625	588	595	602	609	616	623	630	637	644	650	7
626	657	664	671	678	685	692	699	706	713	720	7
627	727	734	741	748	754	761	768	775	782	789	7
628	796	803	810	817	824	831	837	844	851	858	7
629	865	872	879	886	893	900	906	913	920	927	7
630	934	941	948	955	962	969	975	982	989	996	7
631	80 003	010	017	024	030	037	044	051	058	065	7
632	072	079	085	092	099	106	113	120	127	134	7
633	140	147	154	161	168	175	182	188	195	202	7
634	209	216	223	229	236	243	250	257	264	271	7
635	277	284	291	298	305	312	318	325	332	339	7
636	346	353	359	366	373	380	387	393	400	407	7
637	414	421	428	434	441	448	455	462	468	475	7
638	482	489	496	502	509	516	523	530	536	543	7
639	550	557	564	570	577	584	591	598	604	611	7
640	618	625	632	638	645	652	659	665	672	679	7
641	686	693	699	706	713	720	726	733	740	747	7
642	754	760	767	774	781	787	794	801	808	814	7
643	821	828	835	841	848	855	862	868	875	882	7
644	889	895	902	909	916	922	929	936	943	949	7
645	956	963	969	976	983	990	996	*003	*010	*017	7
646	81 023	030	037	043	050	057	064	070	077	084	7
647	090	097	104	111	117	124	131	137	144	151	7
648	158	164	171	178	184	191	198	204	211	218	7
649	224	231	238	245	251	258	265	271	278	285	7
650	291	298	305	311	318	325	331	338	345	351	7
651	358	365	371	378	385	391	398	405	411	418	7
652	425	431	438	445	451	458	465	471	478	485	7
653	491	498	505	511	518	525	531	538	544	551	7
654	558	564	571	578	584	591	598	604	611	617	7
655	624	631	637	644	651	657	664	671	677	684	7
656	690	697	704	710	717	723	730	737	743	750	7
657	757	763	770	776	783	790	796	803	809	816	7
658	823	829	836	842	849	856	862	869	875	882	7
659	889	895	902	908	915	921	928	935	941	948	7
660	954	961	968	974	981	987	994	*000	*007	*014	7
661	82 020	027	033	040	046	053	060	066	073	079	7
662	086	092	099	105	112	119	125	132	138	145	7
663	151	158	164	171	178	184	191	197	204	210	7
664	217	223	230	236	243	249	256	263	269	276	7
665	282	289	295	302	308	315	321	328	334	341	7
666	347	354	360	367	373	380	387	393	400	406	7
667	413	419	426	432	439	445	452	458	465	471	7
668	478	484	491	497	504	510	517	523	530	536	7
669	543	549	556	562	569	575	582	588	595	601	7
670	607	614	620	627	633	640	646	653	659	666	7
671	672	679	685	692	698	705	711	718	724	730	6
672	737	743	750	756	763	769	776	782	789	795	6
673	802	808	814	821	827	834	840	847	853	860	6
674	866	872	879	885	892	898	905	911	918	924	6
675	930	937	943	950	956	963	969	975	982	988	6
676	995	*001	*008	*014	*020	*027	*033	*040	*046	*052	6
677	83 059	065	072	078	085	091	097	104	110	117	6
678	123	129	136	142	149	155	161	168	174	181	6
679	187	193	200	206	213	219	225	232	238	245	6
680	251	257	264	270	276	283	289	296	302	308	6
681	315	321	327	334	340	347	353	359	366	372	6
682	378	385	391	398	404	410	417	423	429	436	6
683	442	448	455	461	467	474	480	487	493	499	6
684	506	512	518	525	531	537	544	550	556	563	6
685	569	575	582	588	594	601	607	613	620	626	6
686	632	639	645	651	658	664	670	677	683	689	6
687	696	702	708	715	721	727	734	740	746	753	6
688	759	765	771	778	784	790	797	803	809	816	6
689	822	828	835	841	847	853	860	866	872	879	6
690	885	891	897	904	910	916	923	929	935	942	6
691	948	954	960	967	973	979	985	992	998	*004	6
692	84 011	017	023	029	036	042	048	055	061	067	6
693	073	080	086	092	098	105	111	117	123	130	6
694	136	142	148	155	161	167	173	180	186	192	6
695	198	205	211	217	223	230	236	242	248	255	6
696	261	267	273	280	286	292	298	305	311	317	6
697	323	330	336	342	348	354	361	367	373	379	6
698	386	392	398	404	410	417	423	429	435	442	6
699	448	454	460	466	473	479	485	491	497	504	6
700	510	516	522	528	535	541	547	553	559	566	6
701	572	578	584	590	597	603	609	615	621	628	6
702	634	640	646	652	658	665	671	677	683	689	6
703	696	702	708	714	720	726	733	739	745	751	6
704	757	763	770	776	782	788	794	800	807	813	6
705	819	825	831	837	844	850	856	862	868	874	6
706	880	887	893	899	905	911	917	924	930	936	6
707	942	948	954	960	967	973	979	985	991	997	6
708	85 003	009	016	022	028	034	040	046	052	058	6
709	065	071	077	083	089	095	101	107	114	120	6
N	O	1	2	3	4	5	6	7	8	9	D

*Use next highest number, as indicated in column "O," for the first two digits.

TABLE 18-O (Continued)—Common Logarithms of Numbers

710–879

N	O	1	2	3	4	5	6	7	8	9	D	N	O	1	2	3	4	5	6	7	8	9	D
710	126	132	138	144	150	156	163	169	175	181	6	795	90 037	042	048	053	059	064	069	075	080	086	5
711	187	193	199	205	211	217	224	230	236	242	6	796	091	097	102	108	113	119	124	129	135	140	5
712	248	254	260	266	272	278	285	291	297	303	6	797	146	151	157	162	168	173	179	184	189	195	5
713	309	315	321	327	333	339	345	352	358	364	6	798	200	206	211	217	222	227	233	238	244	249	5
714	370	376	382	388	394	400	406	412	418	425	6	799	255	260	266	271	276	282	287	293	298	304	5
715	431	437	443	449	455	461	467	473	479	485	6	800	309	314	320	325	331	336	342	347	352	358	5
716	491	497	503	509	516	522	528	534	540	546	6	801	363	369	374	380	385	390	396	401	407	412	5
717	552	558	564	570	576	582	588	594	600	606	6	802	417	423	428	434	439	445	450	455	461	466	5
718	612	618	625	631	637	643	649	655	661	667	6	803	472	477	482	488	493	499	504	509	515	520	5
719	673	679	685	691	697	703	709	715	721	727	6	804	526	531	536	542	547	553	558	563	569	574	5
720	733	739	745	751	757	763	769	775	781	788	6	805	580	585	590	596	601	607	612	617	623	628	5
721	794	800	806	812	818	824	830	836	842	848	6	806	634	639	644	650	655	660	666	671	677	682	5
722	854	860	866	872	878	884	890	896	902	908	6	807	687	693	698	703	709	714	720	725	730	736	5
723	914	920	926	932	938	944	950	956	962	968	6	808	741	747	752	757	763	768	773	779	784	789	5
724	974	980	986	992	998	*004	*010	*016	*022	*028	6	809	795	800	806	811	816	822	827	832	838	843	5
725	86 034	040	046	052	058	064	070	076	082	088	6	810	849	854	859	865	870	875	881	886	891	897	5
726	094	100	106	112	118	124	130	136	141	147	6	811	902	907	913	918	924	929	934	940	945	950	5
727	153	159	165	171	177	183	189	195	201	207	6	812	956	961	966	972	977	982	988	993	998	*004	5
728	213	219	225	231	237	243	249	255	261	267	6	813	91 009	014	020	025	030	036	041	046	052	057	5
729	273	279	285	291	297	303	308	314	320	326	6	814	062	068	073	078	084	089	094	100	105	110	5
730	332	338	344	350	356	362	368	374	380	386	6	815	116	121	126	132	137	142	148	153	158	164	5
731	392	398	404	410	415	421	427	433	439	445	6	816	169	174	180	185	190	196	201	206	212	217	5
732	451	457	463	469	475	481	487	493	499	504	6	817	222	228	233	238	243	249	254	259	265	270	5
733	510	516	522	528	534	540	546	552	558	564	6	818	275	281	286	291	297	302	307	312	318	323	5
734	570	576	581	587	593	599	605	611	617	623	6	819	328	334	339	344	350	355	360	365	371	376	5
735	629	635	641	646	652	658	664	670	676	682	6	820	381	387	392	397	403	408	413	418	424	429	5
736	688	694	700	705	711	717	723	729	735	741	6	821	434	440	445	450	455	461	466	471	477	482	5
737	747	753	759	764	770	776	782	788	794	800	6	822	487	492	498	503	508	514	519	524	529	535	5
738	806	812	817	823	829	835	841	847	853	859	6	823	540	545	551	556	561	566	572	577	582	587	5
739	864	870	876	882	888	894	900	906	911	917	6	824	593	598	603	609	614	619	624	630	635	640	5
740	923	929	935	941	947	953	958	964	970	976	6	825	645	651	656	661	666	672	677	682	687	693	5
741	982	988	994	999	*005	*011	*017	*023	*029	*035	6	826	698	703	709	714	719	724	730	735	740	745	5
742	87 040	046	052	058	064	070	075	081	087	093	6	827	751	756	761	766	772	777	782	787	793	798	5
743	099	105	111	116	122	128	134	140	146	151	6	828	803	808	814	819	824	829	834	840	845	850	5
744	157	163	169	175	181	186	192	198	204	210	6	829	855	861	866	871	876	882	887	892	897	903	5
745	216	221	227	233	239	245	251	256	262	268	6	830	908	913	918	924	929	934	939	944	950	955	5
746	274	280	286	291	297	303	309	315	320	326	6	831	960	965	971	976	981	986	991	997	*002	*007	5
747	332	338	344	349	355	361	367	373	379	384	6	832	92 012	018	023	028	033	038	044	049	054	059	5
748	390	396	402	408	413	419	425	431	437	442	6	833	065	070	075	080	085	091	096	101	106	111	5
749	448	454	460	466	471	477	483	489	495	500	6	834	117	122	127	132	137	143	148	153	158	163	5
750	506	512	518	523	529	535	541	547	552	558	6	835	169	174	179	184	189	195	200	205	210	215	5
751	564	570	576	581	587	593	599	604	610	616	6	836	221	226	231	236	241	247	252	257	262	267	5
752	622	628	633	639	645	651	656	662	668	674	6	837	273	278	283	288	293	298	304	309	314	319	5
753	679	685	691	697	703	708	714	720	726	731	6	838	324	330	335	340	345	350	355	361	366	371	5
754	737	743	749	754	760	766	772	777	783	789	6	839	376	381	387	392	397	402	407	412	418	423	5
755	795	800	806	812	818	823	829	835	841	846	6	840	428	433	438	443	449	454	459	464	469	474	5
756	852	858	864	869	875	881	887	892	898	904	6	841	480	485	490	495	500	505	511	516	521	526	5
757	910	915	921	927	933	938	944	950	955	961	6	842	531	536	542	547	552	557	562	567	572	578	5
758	967	973	978	984	990	996	*001	*007	*013	*018	6	843	583	588	593	598	603	609	614	619	624	629	5
759	88 024	030	036	041	047	053	058	064	070	076	6	844	634	639	645	650	655	660	665	670	675	681	5
760	081	087	093	098	104	110	116	121	127	133	6	845	686	691	696	701	706	711	716	722	727	732	5
761	138	144	150	156	161	167	173	178	184	190	6	846	737	742	747	752	758	763	768	773	778	783	5
762	195	201	207	213	218	224	230	235	241	247	6	847	788	793	799	804	809	814	819	824	829	834	5
763	252	258	264	270	275	281	287	292	298	304	6	848	840	845	850	855	860	865	870	875	881	886	5
764	309	315	321	326	332	338	343	349	355	360	6	849	891	896	901	906	911	916	921	927	932	937	5
765	366	372	377	383	389	395	400	406	412	417	6	850	942	947	952	957	962	967	973	978	983	988	5
766	423	429	434	440	446	451	457	463	468	474	6	851	993	998	*003	*008	*013	*018	*024	*029	*034	*039	5
767	480	485	491	497	502	508	513	519	525	530	6	852	93 044	049	054	059	064	069	075	080	085	090	5
768	536	542	547	553	559	564	570	576	581	587	6	853	095	100	105	110	115	120	125	131	136	141	5
769	593	598	604	610	615	621	627	632	638	643	6	854	146	151	156	161	166	171	176	181	186	192	5
770	649	655	660	666	672	677	683	689	694	700	6	855	197	202	207	212	217	222	227	232	237	242	5
771	705	711	717	722	728	734	739	745	750	756	6	856	247	252	258	263	268	273	278	283	288	293	5
772	762	767	773	779	784	790	795	801	807	812	6	857	298	303	308	313	318	323	328	334	339	344	5
773	818	824	829	835	840	846	852	857	863	868	6	858	349	354	359	364	369	374	379	384	389	394	5
774	874	880	885	891	897	902	908	913	919	925	6	859	399	404	409	414	420	425	430	435	440	445	5
775	930	936	941	947	953	958	964	969	975	981	6	860	450	455	460	465	470	475	480	485	490	495	5
776	986	992	997	*003	*009	*014	*020	*025	*031	*037	6	861	500	505	510	515	520	526	531	536	541	546	5
777	89 042	048	053	059	064	070	076	081	087	092	6	862	551	556	561	566	571	576	581	586	591	596	5
778	098	104	109	115	120	126	131	137	143	148	6	863	601	606	611	616	621	626	631	636	641	646	5
779	154	159	165	170	176	182	187	193	198	204	6	864	651	656	661	666	671	676	682	687	692	697	5
780	209	215	221	226	232	237	243	248	254	260	6	865	702	707	712	717	722	727	732	737	742	747	5
781	265	271	276	282	287	293	298	304	310	315	6	866	752	757	762	767	772	777	782	787	792	797	5
782	321	326	332	337	343	348	354	360	365	371	6	867	802	807	812	817	822	827	832	837	842	847	5
783	376	382	387	393	398	404	409	415	421	426	6	868	852	857	862	867	872	877	882	887	892	897	5
784	432	437	443	448	454	459	465	470	476	481	6	869	902	907	912	917	922	927	932	937	942	947	5
785	487	492	498	504	509	515	520	526	531	537	6	870	952	957	962	967	972	977	982	987	992	997	5
786	542	548	553	559	564	570	575	581	586	592	6	871	94 002	007	012	017	022	027	032	037	042	047	5
787	597	603	609	614	620	625	631	636	642	647	6	872	052	057	062	067	072	077	082	086	091	096	5
788	653	658	664	669	675	680	686	691	697	702	6	873	101	106	111	116	121	126	131	136	141	146	5
789	708	713	719	724	730	735	741	746	752	757	6	874	151	156	161	166	171	176	181	186	191	196	5
790	763	768	774	779	785	790	796	801	807	812	5	875	201	206	211	216	221	226	231	236	240	245	5
791	818	823	829	834	840	845	851	856	862	867	5	876	250	255	260	265	270	275	280	285	290	295	5
792	873	878	883	889	894	900	905	911	916	922	5	877	300	305	310	315	320	325	330	335	340	345	5
793	927	933	938	944	949	955	960	966	971	977	5	878	349	354	359	364	369	374	379	384	389	394	5
794	982	998	993	998	*004	*009	*015	*020	*026	*031	5	879	399	404	409	414	419	424	429	433	438	443	5
N	O	1	2	3	4	5	6	7	8	9	D	N	O	1	2	3	4	5	6	7	8	9	D

*Use next highest number, as indicated in column "O," for the first two digits.

TABLE 18-O (Continued)—Common Logarithms of Numbers

880-999

N	O	1	2	3	4	5	6	7	8	9	D	N	O	1	2	3	4	5	6	7	8	9	D
880	448	453	458	463	468	473	478	483	488	493	5	940	313	317	322	327	331	336	340	345	350	354	5
881	498	503	507	512	517	522	527	532	537	542	5	941	359	364	368	373	377	382	387	391	396	400	5
882	547	552	557	562	567	571	576	581	586	591	5	942	405	410	414	419	424	428	433	437	442	447	5
883	596	601	606	611	616	621	626	630	635	640	5	943	451	456	460	465	470	474	479	483	488	493	5
884	645	650	655	660	665	670	675	680	685	689	5	944	497	502	506	511	516	520	525	529	534	539	5
885	694	699	704	709	714	719	724	729	734	738	5	945	543	548	552	557	562	566	571	575	580	585	5
886	743	748	753	758	763	768	773	778	783	787	5	946	589	594	598	603	607	612	617	621	626	630	5
887	792	797	802	807	812	817	822	827	832	836	5	947	635	640	644	649	653	658	663	667	672	676	5
888	841	846	851	856	861	866	871	876	880	885	5	948	681	685	690	695	699	704	708	713	717	722	5
889	890	895	900	905	910	915	919	924	929	934	5	949	727	731	736	740	745	749	754	759	763	768	5
890	939	944	949	954	959	963	968	973	978	983	5	950	772	777	782	786	791	795	800	804	809	813	5
891	988	993	998	*002	*007	*012	*017	*022	*027	*032	5	951	818	823	827	832	836	841	845	850	855	859	5
892	95 036	041	046	051	056	061	066	071	075	080	5	952	864	868	873	877	882	886	891	896	900	905	5
893	085	090	095	100	105	109	114	119	124	129	5	953	909	914	918	923	928	932	937	941	946	950	5
894	134	139	143	148	153	158	163	168	173	177	5	954	955	959	964	968	973	978	982	987	991	996	5
895	182	187	192	197	202	207	211	216	221	226	5	955	98 000	005	009	014	019	023	028	032	037	041	5
896	231	236	240	245	250	255	260	265	270	274	5	956	046	050	055	059	064	068	073	078	082	087	5
897	279	284	289	294	299	303	308	313	318	323	5	957	091	096	100	105	109	114	118	123	127	132	5
898	328	332	337	342	347	352	357	361	366	371	5	958	137	141	146	150	155	159	164	168	173	177	5
899	376	381	386	390	395	400	405	410	415	419	5	959	182	186	191	195	200	204	209	214	218	223	5
900	424	429	434	439	444	448	453	458	463	468	5	960	227	232	236	241	245	250	254	259	263	268	5
901	472	477	482	487	492	497	501	506	511	516	5	961	272	277	281	286	290	295	299	304	308	313	5
902	521	525	530	535	540	545	550	554	559	564	5	962	318	322	327	331	336	340	345	349	354	358	5
903	569	574	578	583	588	593	598	602	607	612	5	963	363	367	372	376	381	385	390	394	399	403	5
904	617	622	626	631	636	641	646	650	655	660	5	964	408	412	417	421	426	430	435	439	444	448	5
905	665	670	674	679	684	689	694	698	703	708	5	965	453	457	462	466	471	475	480	484	489	493	4
906	713	718	722	727	732	737	742	746	751	756	5	966	498	502	507	511	516	520	525	529	534	538	4
907	761	766	770	775	780	785	789	794	799	804	5	967	543	547	552	556	561	565	570	574	579	583	4
908	809	813	818	823	828	832	837	842	847	852	5	968	588	592	597	601	605	610	614	619	623	628	4
909	856	861	866	871	875	880	885	890	895	899	5	969	632	637	641	646	650	655	659	664	668	673	4
910	904	909	914	918	923	928	933	938	942	947	5	970	677	682	686	691	695	700	704	709	713	717	4
911	952	957	961	966	971	976	980	985	990	995	5	971	722	726	731	735	740	744	749	753	758	762	4
912	999	*004	*009	*014	*019	*023	*028	*033	*038	*042	5	972	767	771	776	780	784	789	793	798	802	807	4
913	96 047	052	057	061	066	071	076	080	085	090	5	973	811	816	820	825	829	834	838	843	847	851	4
914	095	099	104	109	114	118	123	128	133	137	5	974	856	860	865	869	874	878	883	887	892	896	4
915	142	147	152	156	161	166	171	175	180	185	5	975	900	905	909	914	918	923	927	932	936	941	4
916	190	194	199	204	209	213	218	223	227	232	5	976	945	949	954	958	963	967	972	976	981	985	4
917	237	242	246	251	256	261	265	270	275	280	5	977	989	994	998	*003	*007	*012	*016	*021	*025	*029	4
918	284	289	294	298	303	308	313	317	322	327	5	978	99 034	038	043	047	052	056	061	065	069	074	4
919	332	336	341	346	350	355	360	365	369	374	5	979	078	083	087	092	096	100	105	109	114	118	4
920	379	384	388	393	398	402	407	412	417	421	5	980	123	127	131	136	140	145	149	154	158	162	4
921	426	431	435	440	445	450	454	459	464	468	5	981	167	171	176	180	185	189	193	198	202	207	4
922	473	478	483	487	492	497	501	506	511	515	5	982	211	216	220	224	229	233	238	242	247	251	4
923	520	525	530	534	539	544	548	553	558	562	5	983	255	260	264	269	273	277	282	286	291	295	4
924	567	572	577	581	586	594	595	600	605	609	5	984	300	304	308	313	317	322	326	330	335	339	4
925	614	619	624	628	633	638	642	647	652	656	5	985	344	348	352	357	361	366	370	374	379	383	4
926	661	666	670	675	680	685	689	694	699	703	5	986	388	392	396	401	405	410	414	419	423	427	4
927	708	713	717	722	727	731	736	741	745	750	5	987	432	436	441	445	449	454	458	463	467	471	4
928	755	759	764	769	774	778	783	788	792	797	5	988	476	480	484	489	493	498	502	506	511	515	4
929	802	806	811	816	820	825	830	834	839	844	5	989	520	524	528	533	537	542	546	550	555	559	4
930	848	853	858	862	867	872	876	881	886	890	5	990	564	568	572	577	581	585	590	594	599	603	4
931	895	900	904	909	914	918	923	928	932	937	5	991	607	612	616	621	625	629	634	638	642	647	4
932	942	946	951	956	960	965	970	974	979	984	5	992	651	656	660	664	669	673	677	682	686	691	4
933	988	993	997	*002	*007	*011	*016	*021	*025	*030	5	993	695	699	704	708	712	717	721	726	730	734	4
934	97 035	039	044	049	053	058	063	067	072	077	5	994	739	743	747	752	756	760	765	769	774	778	4
935	081	086	090	095	100	104	109	114	118	123	5	995	782	787	791	795	800	804	808	813	817	822	4
936	128	132	137	142	146	151	155	160	165	169	5	996	826	830	835	839	843	848	852	856	861	865	4
937	174	179	183	188	192	197	202	206	211	216	5	997	870	874	878	883	887	891	896	900	904	909	4
938	220	225	230	234	239	243	248	253	257	262	5	998	913	917	922	926	930	935	939	944	948	952	4
939	267	271	276	280	285	290	294	299	304	308	5	999	957	961	965	970	974	978	983	987	991	996	4
N	O	1	2	3	4	5	6	7	8	9	D	N	O	1	2	3	4	5	6	7	8	9	D

*Use next highest number, as indicated in column "O," for the first two digits.

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This list of publications is not intended as a complete bibliography of books covering the field of electrical metering. It does, however, present material which has been recommended by members of the Meter and Service Committee of Edison Electric Institute and which they have found useful in the operation of a meter department and in the training of personnel.

There is a wealth of material which has been prepared by the manufacturers of meters and instruments. This list is so extensive that it has been omitted from this publication but such material is available upon request to the various manufacturers.

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MS-3 Specifications for Standard Current Transformers for Primary Circuits.
MS-4 Specifications for Indicating and Cumulative Demand Register Scales.
MS-5 Specifications for Indicating Thermal Watt Demand Meters.
MS-6 Specifications for Marking and Arrangement of Terminals for Phase-Shifting Devices Used in Metering.

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APPENDIX

This appendix consists of excerpts from the meter manufacturers' sections of the fourth edition of the *Handbook for Electrical Metermen,* published in 1923.

It contains descriptive data of the older types of meters, many of which are still in use. Tables of constants for these meters, however, will be found in Sections 13 to 16 of this edition.

Duncan Watthour Meters 525-539

General Electric Watthour Meters 541-559

Sangamo Watthour Meters 561-578

Westinghouse Watthour Meters 579-600

Originally prepared by the

METER COMMITTEE

TECHNICAL NATIONAL SECTION

NATIONAL ELECTRIC LIGHT ASSOCIATION

Data from 1923 edition of Handbook for Electrical Metermen

DUNCAN WATTHOUR METERS

Duncan watthour meters are manufactured by the Duncan Electric Manufacturing Company, of Lafayette, Indiana.

DESCRIPTION OF DIRECT-CURRENT TYPES.—The Duncan direct-current meters depend upon the principle of the electrodynamometer for their operation, in which the interaction of the magnetic flux produced by the currents in the field coils with the currents in a pivoted armature, produces motion of the latter. It also embodies the two necessary watthour meter elements required for speed control and registration of the revolutions of the armature, these being the drag magnet and disk, and the meter register, respectively. A continuous torque is obtained by the use of a commutator and brushes, the commutator segments being connected to the armature coils and carried on the same spindle therewith.

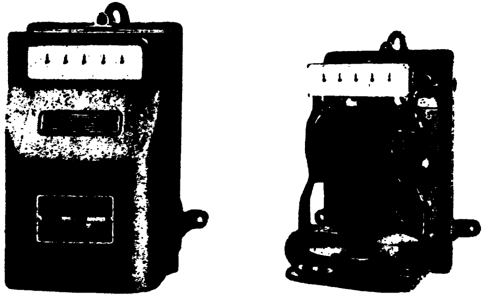


FIG. 381.—Duncan Model A Direct-current Watthour Meter.

Model A Watthour Meters.—Duncan Model A Watthour Meter (Fig. 381) is a general name employed to designate the house-type watthour meters manufactured by this company from 1902 to the summer of 1908. The serial numbers on these watthour meters are less than 76,000 and they are distinguished from later types by the fact that their registers have five dials.

Construction Features.—The meter has two field coils situated on opposite sides of an armature, the latter being carried by a shaft which also carries an aluminum braking disk and a commutator. The majority of these watthour meters have light-load compensating coils of 1000 turns each, wound in ten sections with taps brought out to a multipoint switch so arranged that the number of turns in the potential circuit can be increased or decreased by shifting the switch arm, thus varying the starting torque for light-load compensation.

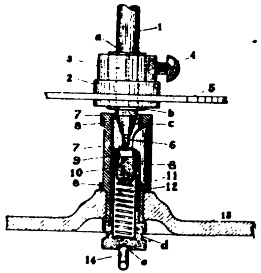


FIG. 382.—Sectional View of Visual Bearing and Threadless Jewel Post.

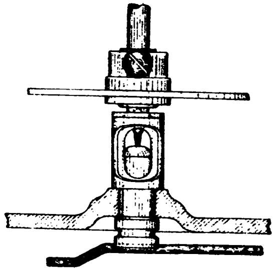


FIG. 383.—Visual Bearing Open (Front View).

1. Spindle.
2. Hub of aluminum disk.
3. Ring for clamping split extension of hub to spindle.
4. Set screw for clamping ring.
5. Aluminum retarding disk.
6. Detachable spindle point.
7. Top of support for collar and jewel bearing.
8. Visual bearing collar.
9. Oriental sapphire jewel bearing.
10. Jewel stud.
11. Jewel spring.
12. Jewel post.
13. Meter base.
14. Wire retaining spring.

a. Split extension of hub.
b. Stop to rest on 7 when jewel post is lowered.
c. Lower and tapered portion of spindle.
d. Jewel post shipping groove.
e. Jewel post service groove.

The armature consists of eight coils, each coil having 1000 turns of No. 40 B. & S. gauge single silk covered wire. The commutators have eight segments each.

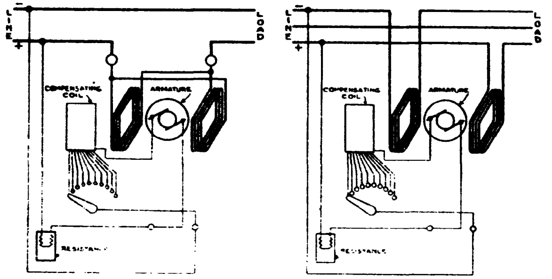
The base of this meter is an aluminum casting. The arch and shelf are brass castings. The cover is made of sheet zinc and provided with a window over the register face only.

Bearings.—This type of watthour meter is equipped with a threadless jewel post, held in place by a wire retaining spring, which engages the bottom or side of the post, according to whether the jewel is in place or is lowered for transportation.

A cupped jewel, step or lower bearing, made from Australian sapphire, is used except in the larger sizes of watthour meters (that is, above 600 amperes in house type, and over 1000 amperes in switchboard type), in which a cupped diamond jewel is used.

The spindle point, or that portion of the shaft which rests upon the sapphire cup, is detachable and is held in position at the bottom of the spindle by magnetism. A type of step bearing is used in these meters which permits a visual inspection of the jewel and pivot while the meter is in operation (Figs. 382 and 383).

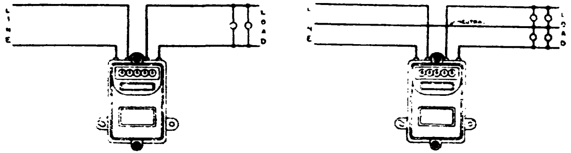
INTERNAL CONNECTION DIAGRAMS



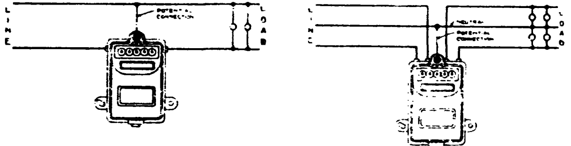
Two-wire. Three-wire.

Fig. 384.—Internal Connections for Duncan Model A Direct-current Watthour Meters.

EXTERNAL CONNECTION DIAGRAMS



2-Wire, 4-Terminal Type, Internal Potential connection. 3-Wire, 4-Terminal Type, Internal Potential connection.



2-wire, 3-Terminal Type, External Potential connection. 3-Wire, 5-Terminal Type, External Potential connection.

Fig. 385.—External Connections for Duncan Model A Direct-current Watthour Meters.

Model D Watthour Meters.—The Model D Duncan Watthour Meter was especially designed to meet the requirements of some of the smaller lighting plants which did not care to purchase the higher priced or high-torque Duncan meters.

Construction Features.—Its construction consists of top and bottom castings joined by two rods. Upon the lower casting or shelf are situated the two retarding magnets, also the lower jewel bearing. The two vertical rod supports carry the two series field coils, also the compensating coil and switch, and near the upper extremity the register is mounted. The incoming wires to this meter pass through suitable bushings provided in the top casting. The top casting also contains the three points of suspension or support for the meter when installed. The cover is put on from the bottom and held in position by means of two wing nuts screwed to threaded extensions of the supporting rods which project at the bottom.

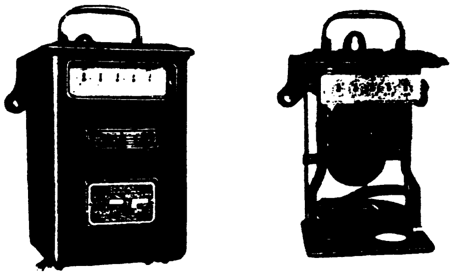


Fig. 386.—External and Internal View of Duncan Model D Direct-current Watthour Meter.

The resistance that is placed in series with the armature is of the disk or pancake form. The armature, while smaller in size than that used in any of the other models, has the same number of turns and is provided with eight coils.

This meter differs from all house-type meters now on the market in that it is provided with a carrying handle, as shown in the cuts. Many of these meters were calibrated and sold for alternating-current service. The last one made was numbered 103,601 (Fig. 386).

The test constants for these meters were marked on the rotating element and represented 60 times the number of watthours per revolution of the rotating element. The watthour constant equals the test constant divided by 60. The watt-second constant equals 60 times the test constant.

Model E Watthour Meters.—The Model E Watthour Meter (Fig. 387) is a development of the Model A, retaining practically the same electrical characteristics but differing considerably from the older type in mechanical construction.

Construction Features.—In this meter all metal parts including the base, arch, shelf and cover, are formed from heavy sheet metal, on punch presses by means of dies. The armature winding is the same as in the Model A, but the light-load compensating coil has but 400 turns, divided into 10 sections. On account of the lighter rotating element and reduced friction the starting torque or light-load compensation is reduced considerably. In 1916 the rheostat-type compensating coil was replaced with the swinging type coil.

The cover is made of sheet metal with glass windows over the register face and over the disk.

Ratings.—These meters were originally made 2-wire in ratings from 2½ to 600 amperes inclusive, for 110, 220 and 550 volts, and three-wire from 2½ to 300 amperes, inclusive, for 220 and 550 volts.

This model was produced between June 1908 and March 1912, with serial numbers from 76,000 to 150,000; from March 1912 to present date, this model, with the exception of the 2½, 5, 10 and 15 ampere ratings, has been manufactured in serial numbers above 150,000, although several minor improvements have been included from time to time.

Model E meters having serial numbers larger than 150,000 are practically the same in electrical and mechanical design as those having serial numbers from 76,000 to 150,000, excepting that those above 150,000 are provided with a new system of registering trains and a new type of plain dials bearing the words "Kilowatt Hours" only.

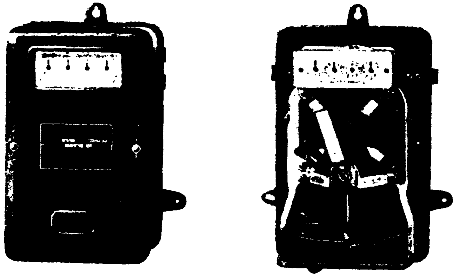


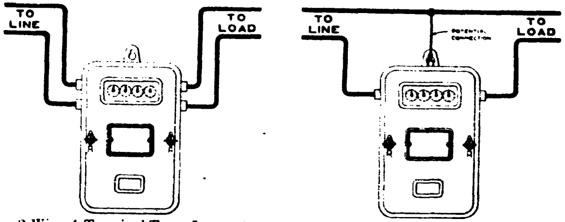
FIG. 387.—Model E Watthour Meter, with and without Cover.

The test constant (watthour constant) is marked on the bracket supporting the compensating switch in the earlier meters of this type and represents the watthours per revolution of the rotating element. In the later meters having the swinging-type compensating coil, the watthour constant is stamped on the right hand frame support and the serial number on the left support.

Model EA Watthour Meters.—The Duncan Model EA Watthour Meter (Fig. 389) is similar in construction to the Model E in all details except that the armature and field coils are arranged astatically. This combination is secured by connecting the coils so as to give a 4-pole field and by using a 4-pole wave wound armature having 17 coils.

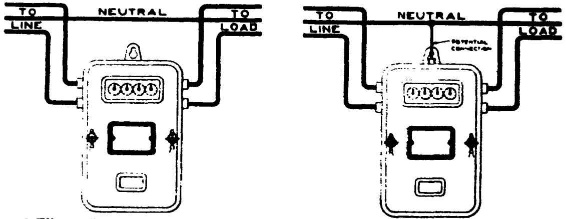
In all particulars except the armature and field construction, this meter corresponds and is similar to the Model E.

This model was produced in January, 1912.



2-Wire, 4-Terminal Type, Internal Potential Connection.

2-Wire, 3-Terminal Type, External Potential Connection.

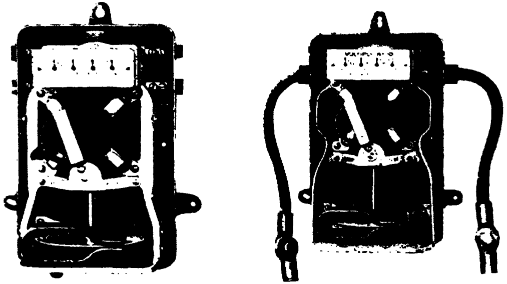


3-Wire, 4-Terminal Type, Internal Potential Connection.

3-Wire, 5-Terminal Type, External Potential Connection.

FIG. 388.—External Connections for Duncan Model E Direct-current Watthour Meter.

Model EC Watthour Meters.—The Model EC embodies the same principle and mechanical construction as the Model E, except that it is provided with a junction box for the binding posts, a register which has a small test dial, and a case equipped with a sealing cup, all of which conforms to the requirements of the Canadian Government.



a b

FIG. 389.—(a) Duncan Model E Watthour Meter, 50 Amperes, Three-wire. (b) Duncan Model E Watthour Meter, 100 to 600 Amperes, Two-wire.

Changes in the Model E Meters.—In 1910 the smaller ratings of the Model E were changed somewhat so as to make a lighter and more compact meter. These changes were made in the 5, 10 and 15 ampere ratings and the 2½ ampere rating was eliminated. The electrical characteristics remained practically the same, while the rearrangement of parts enabled the meter to be made smaller in size and lighter in weight. At first the rheostat type of compensating coil was used but later the swinging-type coil was used.

In 1922 further improvements were made in this type of meter. The series coils were wound with copper wire having five coats of enamel instead of two layers of cotton. The construction of the frame was altered so as to make the brushes more accessible and give more room for inspection and cleaning of the commutator. Braces were added so that the construction is somewhat similar to bridge construction. The positions of the magnets were altered, so that they are mounted at a point closer to the base. The type of armature and brush construction, the swinging-type compensating coil, and other well-known features remain practically the same as before. The only change in the manufacturing practice not mentioned is the use of a small spot of magnetic paint on the disk, as an anti-creep device.

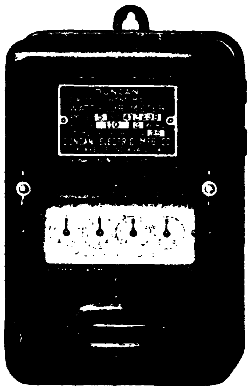
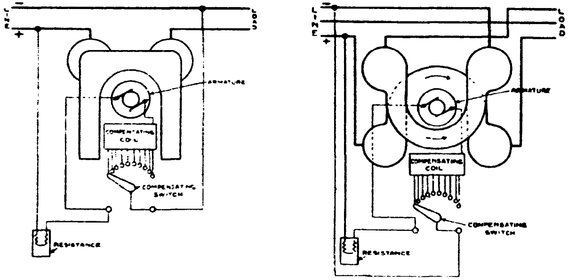


FIG. 390.—External View of Duncan (Small Size) Model E Direct-current Watthour Meter.

Model EK Watthour Meters.—The Model EK meter was developed in the fall of 1922 to meet the demand for a bottom-connected, commutator-type, direct-current watthour meter. In this type of meter the leads from the series field coils are brought down side by side, so that the fields produced by the current in these leads will neutralize each other. The shape of the terminal box is such that the same meter trim can be used as is used for the Model M2 alternating-current meter. These meters have removable terminal blocks. Tables of test constants for this type meter follow.

Model C (Self-contained) Switchboard-type Meters.—This watthour meter (Fig. 392) is a series type of switchboard meter and was built 2-wire in all ratings from 100 to 6000 amperes, 110, 220 or 550 volts, and 3-wire from 100 to 3000 amperes, 220 or 550 volts. In ratings from 100 to 600 amperes inclusive the coils are wound of strip copper. In ratings from 800 amperes up the coils are made of copper castings. The series fields in all types are arranged to give four poles, and a wave-wound 4-pole armature is used so as to render the meter astatic. The armature consists of 17 coils and is connected to a 17-segment commutator. This meter is given special finishes so as to adapt it for use on switchboards. The cover is entirely of glass.

Model F (Self-contained) Switchboard-type Meters.—The Duncan Model F watthour meter is similar to the Model C in electrical design and in the general mechanical construction, but differs from



Two-wire. Three-wire.

FIG. 391.—Internal Connections for Duncan Model C, Switchboard, Direct-current Watthour Meters.

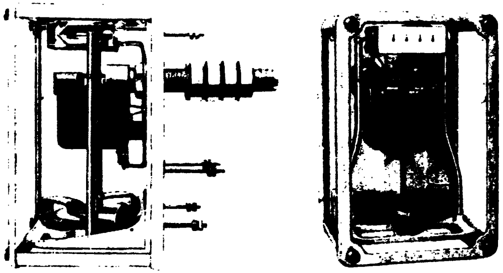


FIG. 392.—External Views of Duncan Model C, Switchboard, Direct-current Watthour Meters.

the Model C in having a sheet metal cover with a glass front. This type is regularly made two-wire in ratings from 100 to 1000 amperes, 110, 220 or 550 volts, and three-wire from 100 to 1000 amperes inclusive, 220 or 550 volts. The test constants, series coil data, etc., are the same as for the Model C.

This model was produced in June, 1909.

Model R, Shunted Type, Switchboard Meters.—The Duncan Model R switchboard watthour meter (Fig. 395) is a shunted type of watthour meter very similar in principles of operation to the Model E, house-type meter.

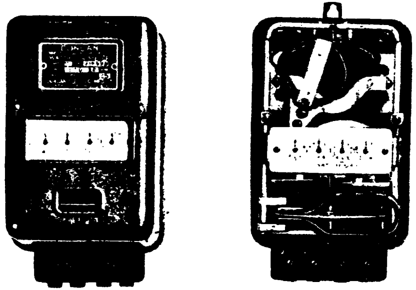


FIG. 393.—Duncan Model EK, Direct-current Watthour Meter.

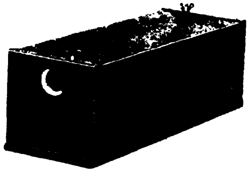


FIG. 394.—Shunt Cover for use with Model ER Shunt.

Series Coils.—The meter has four field coils so connected as to set up a four-pole astatic field. Two field coils are connected in series and, up to meter No. 173,492, each pair took 20 amperes at full load. On these meters, the two-wire watthour meter took 40 amperes from the shunt (20 amperes for each pair of field coils), while the three-wire meters were provided with two shunts from each of which was taken 20 amperes. All shunts for meters taking this type of mechanism are calibrated so as to have an 80 millivolt drop at full-load rating of meter less the current taken by the meter.

From No. 173,492 to No. 175,944, the current required by each pair of field coils was 10 amperes on full load, instead of 20 amperes as in those previous to this serial number.

Beginning with serial No. 216,613 the field current taken by each pair of series coils was changed to 15 amperes. At the same time, the armature current was reduced and additional friction compensation added in the way of a second compensating coil and switch.

These meters have a nameplate on the shelf which gives the full-load current and the watthour test constant independent of the shunt.

Armature.—The armature is purposely made large in diameter and light in weight and is wave wound so as to develop a four-pole astatic field using only two brushes set at right angles to each other.

General Construction Features.—The Model R was furnished with a plate glass cover up to serial No. 216,613. Beginning with this serial number a glass cover built with an extruded metal frame was supplied. This cover is not only stronger but greatly improves the general appearance of the meter. The interior parts are polished, enameled, plated, or otherwise finished to order for switchboard mounting. Each meter is furnished with five-foot leads but may be provided with longer leads if desired. The meter was originally supplied with a gold commutator but is now equipped with one of pure silver. In accordance with usual Duncan practice for switchboard meters a diamond jewel bearing is provided.

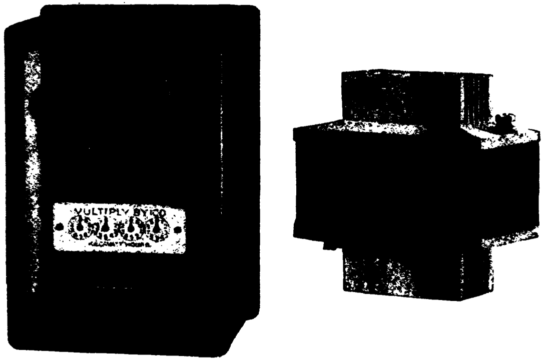


FIG. 395.—External View of Duncan Model R, Switchboard, Shunted Type, Direct-current Watthour Meter and Shunt.

A diagram of internal connections is shown in Fig. 397.

The test constants, ratios and testing formulas are the same as those used with the Duncan Model E meters.

These meters are made in ratings from 100 amperes to 20,000 amperes, although larger sizes can be furnished if desired.

This model was produced in September, 1911.

Model ER, Shunted Type, Watthour Meters.—The Duncan, Model ER watthour meter consists of the Model R mechanism assembled on the Model E base and is built with front connections. The changes made in the field coils of the Model R also apply to the Model ER. This meter is very similar to the Model FR, excepting the Model ER is front connected while the Model FR is back connected (Fig. 396).

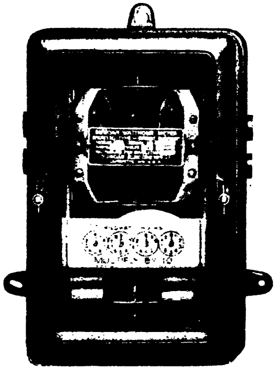


FIG. 396.—External View of Duncan Model ER, Shunted Type, Direct-current Watthour Meter.

This type is built in sizes from 100 to 20,000 amperes inclusive.

Test constants for this type are the same as for Model R.

This type was produced in January, 1912.

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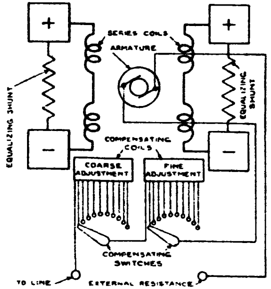
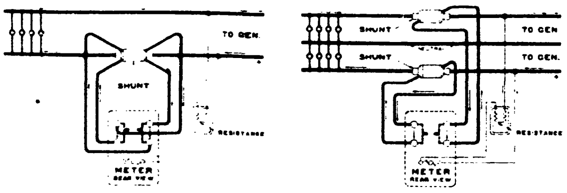
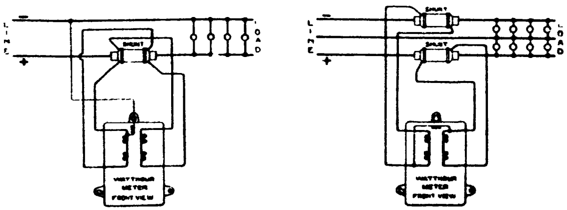


FIG. 397.—Internal Connections for Duncan Model R, Shunted, Switchboard-type, Direct-current Watthour Meter.



Model R, 2-wire.

Model R, 3-wire.



Model ER, 2-wire.

Model ER, 3-wire.

FIG. 398.—External and Internal Diagrams for Duncan Shunted Type, Direct-current Watthour Meters.

Model FR, Shunted Type, Switchboard Meters.—The Duncan Model FR watthour meter consists of the Model R mechanism assembled on a Model F base with a sheet metal cover having an all glass panel front. The changes made in the field coils of the Model R and ER meters also apply to the Model FR. This meter is built in ratings from 100 to 20,000 amperes and replaces the series type Model F switchboard meter in the larger ratings, since the Model F is built in ratings up to 1000 amperes only.

The connections, dimensions of shunts and test constants are the same as for the Model R.

This model was produced in February, 1912.

GENERAL NOTES ON DIRECT-CURRENT WATTHOUR METERS.—Full Load Adjustment.—Full-load adjustments are made as in other types of commutator-type meters by shifting the magnets with respect to the disk.

Light-load Adjustment.—In order to increase the speed of the meter at light loads, the compensating coil should be moved to the right or toward the armature. To decrease the speed of the meter at light load, or if the meter should creep on no load the compensating coil should be moved to the left or away from the armature. Care should be taken to see that the clamping screws are well tightened after adjustment has been made.

The light-load adjustment originally consisted of a multipoint switch for varying the strength of the compensating coil located in front of the series field coil. By moving the switch arm either toward F or S, more or less compensation is obtained as required.

Anti-creep Device.—Duncan direct-current watthour meters as at present manufactured have an anti-creep device in the form of a spot of magnetic paint. This magnetic paint is allowed to dry very hard and is then covered with enamel paint. Enough magnetic paint is used to keep the meter from creeping under ordinary conditions.

The use of magnetic paint in Duncan meters was started about January 1, 1922. Meters shipped before that time do not have this anti-creep device. Samples of this paint may be had from the Duncan factory upon application. In applying it, the disk should be wedged in position by placing strips of paper between the disk and the permanent magnets, and the black spot should be placed as far as possible from the poles of the permanent magnets. The magnetic paint should be allowed to dry for at least twenty-four hours, and following this should be given a coat of black enamel paint, which should also be allowed to dry for a period of twenty-four hours. This magnetic paint can be used in all cases where there is high voltage or excessive vibration, and if the meter is properly calibrated in connection with this spot, it will be accurate on light loads and at the same time will not creep on no load.

DESCRIPTIONS OF DUNCAN ALTERNATING-CURRENT WATTHOUR METERS.—Model M Induction Meters.—The Duncan Model M watthour meter (Fig. 399) is of the induction type. It contains but three coils, one being a potential coil, the other two being current coils. In multiple with the main, or effective air gap, is another air gap. The effective gap, or the one in which the disk operates, is longer than the gap in multiple with it.

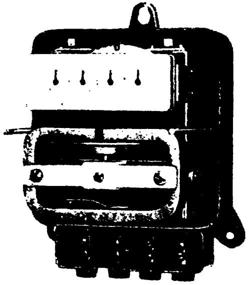


FIG. 399.—Duncan Model M, Single-phase, Induction Watthour Meter.

Adjustments.—All light-load adjustment is secured by another application of a general scheme of multiple gaps. Small soft iron cores are carried on sliding adjustments in front of the potential circuit cores, giving a starting, or compensating torque. To prevent humming, the shaft is provided with a flexible upper bearing. The meter contains one brake magnet and full-load adjustment is secured by shunting the flux of this magnet with a soft iron disk whose position can be changed by micrometer adjustment.

General Features.—This meter is provided with four dials of the same size as all other Duncan watthour meters. The binding posts are contained in a separate compartment located at the bottom of the meter. When ordered for 133 cycles, a special adjustment was provided so that the meters could be changed over to 60 cycles without recalibration.

The test constant is marked on the rotating element and equals 60 times the number of watthours per revolution of the rotating element.

This meter was made in all ratings from 5 to 800 amperes, current transformers being used with all instruments rated 100 amperes or higher.

Test constants for this type of meter are the same as for the Model E, direct-current, house-type meters.

This model was produced in February, 1912.

Diagrams of connections for this meter are given in Fig. 401.

Model M1 Induction Meters.—The Model M1 is similar to the Model M in general appearance and makeup, although it differs from it in a few important details (Fig. 400).

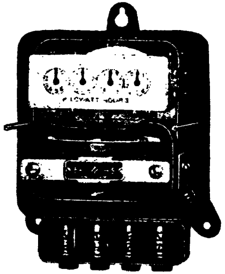


FIG. 400.—Internal View of Duncan Model M1 Induction Watthour Meter.

As in the case of the Model M, a powerful magnet is used which measures fourteen inches from pole to pole and weighs 1⅜ pounds. Such a magnet has great permanence, and thereby enables the meter to retain its original accuracy for long periods of time.

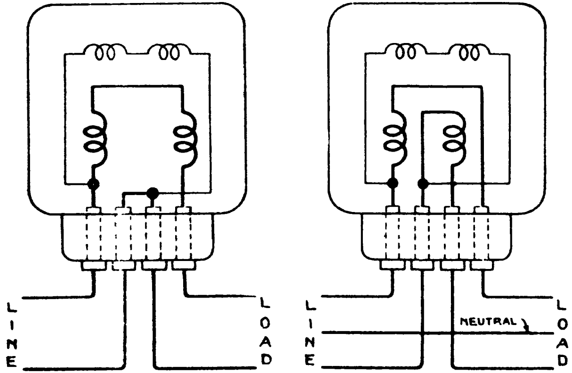
Adjustments.—The light-load adjustment is effected by moving a hollow square of copper in a horizontal plane until the flux from the potential core is slightly unbalanced, thus giving rise to a torque just sufficient to neutralize the friction of the meter.

The light- and full-load adjusting devices are in plain view at the front of the meter just below the poles of the permanent magnet. Between the full-load screw and the light-load lever is a direction plate explaining their use and giving the serial number and test constant of the meter. To increase the speed of the meter for heavy loads, the large knurled head of the full-load screw is turned to the left. To increase the speed on small loads, such as 5% or 10% of the meter's ampere rating, the light-load lever is pushed to the left.

General Features.—Should lightning damage a potential coil, it may be replaced by simply removing the core from the pressed steel grid and slipping off the coil. A new coil may then be put in its place. The construction of the cores is such that this is easily done, thus obviating the expense of purchasing a complete core and coil, the coil itself being the only new part needed.

The entire meter element, including the shaft and its disk, the drag magnet, and the series and potential electromagnets, are supported directly from the heavy pressed steel grid, thus assuring permanent alignment of the various parts.

As in the recent types of Duncan direct-current meters, the register ratio is plainly indicated on the register. The test constant, or watthour constant, appears on the direction plate at the front of the meter.



Two-wire Three-wire.

FIG. 401.—Connection Diagrams of Duncan Model M. Induction Watthour Meters.

Model M2 Single-phase Watthour Meter.—The Model M2 meter was developed in 1915 and is considerably smaller, more compact and more accessible than former Duncan alternating-current watthour meters. The fundamentals or principles of design are somewhat similar to those of the Model M1 but the mechanical construction is radically different. The entire meter element is mounted upon a cast frame or grid so as to form a rigid unit and provide for the permanent alignment of the various parts. The terminal chamber is integral with the cast base and is filled with a fire- and moisture-proof compound to minimize the probability of short circuits when making connections.

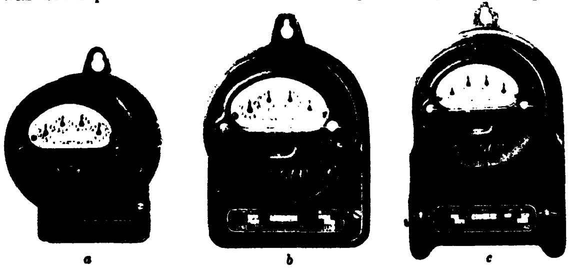


FIG. 402.—Duncan Model M-2 Watthour Meter.
a—5 to 25 amperes, 3-wire, 220 volts
b—50 and 75 amperes, 3-wire, 220 volts
c—100 amperes and above, 3-wire, 220 volts

Adjustments.—The light-load and full-load adjustments are of the micrometer type, and are located in plain sight in front of the meter. The quadrature adjustment is made accessible from the front of the meter after the register is removed. The explanatory view of the Model M2 is shown in Fig. 403. A feature of this meter is the use of only one permanent magnet. The full-load adjustment is accomplished by shunting more or less flux through the disk by means of a soft iron shunt mounted on a micrometer screw. The light-load adjustment is a shading plate actuated by means of a micrometer screw. The inductive load adjustment is accomplished by raising or lowering the two ears projecting through the grid as shown in Fig. 403. Should it appear necessary to change this adjustment, an investigation should be made to make certain that the current coil has not become short circuited.

Electromagnets.—The current and potential electromagnets in this meter are separable, that is, they are mounted on the grid independent of each other. All circuits of this meter may be tested for opens and grounds without disturbing the grid, and for this reason it is seldom necessary to make a visual inspection of the electromagnets. If one of the potential coils is open circuited, the meter, of course, refuses to operate, and if one of them is short circuited, the meter will creep forward or backward according to which potential coil has the short circuit. Short circuits in the current coil will not cause creeping. Although a visual inspection of the electromagnets is seldom necessary, yet they are readily accessible, and the complete meter element, including electromagnets, bearings, permanent magnet and recording train, may be removed from the meter base for inspection, by taking out the four screws holding the grid to the base, and by loosening three binding post screws.

Rotating Element.—The rotating element of the Model M2 meter originally weighed ten grams but the use of a brass shaft instead of one of aluminum alloy increased it to eleven grams. In addition, it is so designed as to have an exceedingly low center of gravity and by this means, the top bearing is relieved of much of its load. The disk is provided with holes, which serve to prevent creeping, unless the meter is out of calibration, or has a short-circuited potential coil.

Bearings.—The lower bearing consists of a cupped sapphire jewel, on which rests a pivot which is inserted in the lower end of the main shaft and which may be easily removed by the use of a Duncan pivot puller. This bearing should be properly oiled from time to time. The top bearing consists of a flexible pin, which projects into a hole in the upper end of the shaft. The hole is self-cleaning to a large extent, and this is especially true of the meters made in recent years, which have a pin of pure nickel wire, which is made very hard and dense by repeated swaging and burnishing. No oil is used in the top bearing of the Model M2 meter.

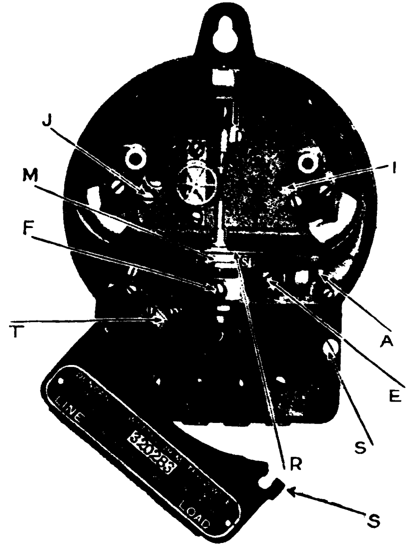


FIG. 403.—Explanatory View of Duncan Model M2 Watthour Meter. Without Register.

Removable Terminal Chamber Cover can be Provided if Desired.

A—Micrometer light-load adjustment.
E—Light-load adjustment clamp screw.
F—Full-load adjustment clamp screw.
I—Inductive load adjustment.
J—Inductive load adjustment clamp screw.
M—Micrometer full-load adjustment
R—Disk.
S—Sealing screw and lug.
T—Test link.

Changes in the Model M2.—Although no radical changes in design have been made since the M2 was first put on the market, detailed improvements have been made from time to time. The original meter had the cover studs mounted on the grid. Later the cover studs were made removable, and in the summer of 1922 a change was made in the binding posts permitting the cover studs to be permanently mounted on the base. The practice of taping potential coils was abandoned so as to improve the appearance and radiating qualities of the coils, also the mechanical strength of the lead connections. Potential leads of solid copper wire, properly insulated and given ample mechanical support have been subsituted for the flexible leads formerly employed. Also strip copper terminals are now supplied with the coils. A clear space one inch high has been provided on the face of the cover as recommended by the Meter Committee of the National Electric Light Association. The full- and light-load adjustment screws have been marked with arrows and the letters F and S and a spring put on the light-load adjustment to take up back lash, making the adjustment positive.

The cover has been reinforced so as to withstand greater pressures, and so as to render it less subject to damage in shipment. The number of rivets holding the glass cover has been reduced. The upper part of the grid through which the top bearing passes has been channelled so that the top bearing is more readily removable. The middle sized base (50 and 75 amperes) has been changed, making these sizes more accessible and pleasing in appearance.

The Duncan Model M2 can be provided with a removable terminal chamber cover which facilitates installing the meter in connection with certain service boxes.

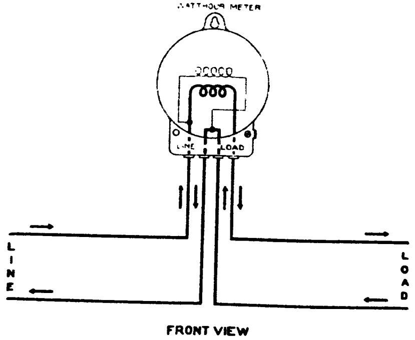


FIG. 404.—Connections of 2-wire Duncan Model M2 watthour meter 5 to 100 amperes, 600 volts and less.

Data from 1923 edition of Handbook for Electrical Metermen

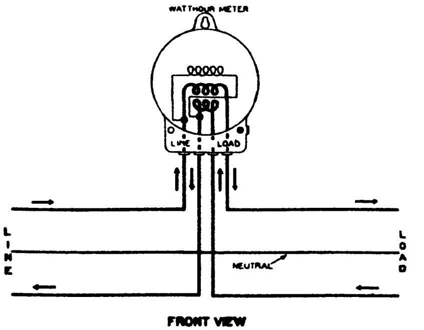


FIG. 405.—Connections of 3-wire Duncan Model M2 watthour meter, 5 to 150 amperes, 600 volts and less.

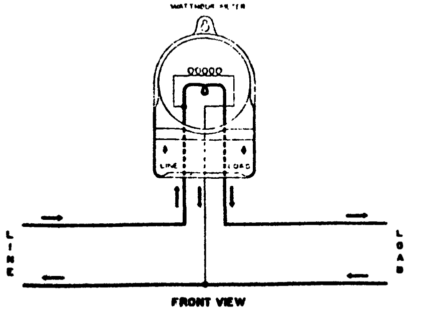


FIG. 406.—Connections of 2-wire Duncan Model M2 watthour meter, 150 to 300 amperes, 600 volts and less.

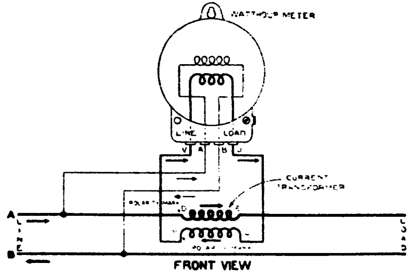


FIG. 407.—Connections of 2-wire Duncan Model M2 watthour meter, with current transformer, 400 amperes and above, 600 volts and less.

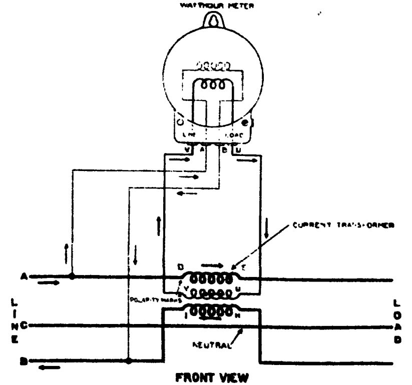
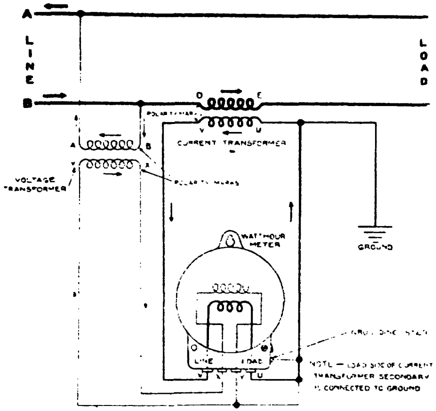


FIG. 408.—Connections of Duncan Model M2 watthour meter. 3-wire, 200 amperes and above, 600 volts and less.



FRONT VIEW

FIG. 409.—Connections of Duncan Model M2 watthour meter, 2-wire, with current and voltage transformers, all ampere capacities, 650 volts and above.

Self-contained Large-capacity Meters.—The Model M2 is built for 2- and 3-wire circuits in the small size base with ratings from 5 to 25 amperes, and 600 volts and less. A medium size base is used to house the 2- and 3-wire sizes rated at 50 and 75 amperes, and a large sized base is employed for the 2-wire meters from 100 to 300 amperes, inclusive, and for 3-wire meters of 100 and 150 amperes.

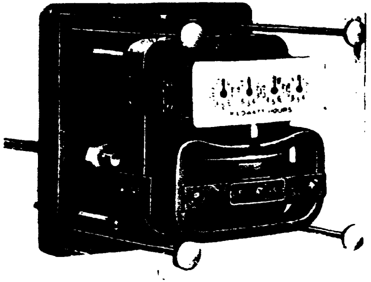


FIG. 410.—External View of Duncan Model MS Switchboard-type, Induction Watthour Meter.

Model MS Induction Switchboard-type Meters.—The Model MS switchboard type is an alternating-current meter and embodies the same electrical principle as the Model M1, but is mounted on a base for switchboard mounting and is furnished in dull black, polished nickel and polished copper. It was made in ratings from 5 amperes up. Current transformers are used on ratings from 100 amperes up for 2-wire meters and from 75 amperes up for 3-wire meters. Both potential and current transformers are used for meters above 440 volts.

Model M2P Polyphase Induction Watthour Meter.—The Model M2P is very similar to the Model M2 and most of the parts are interchangeable, the M2P being a combination of two Model M2 single-phase meters, mounted within a common base, upon a common grid, and driving a common shaft and register.

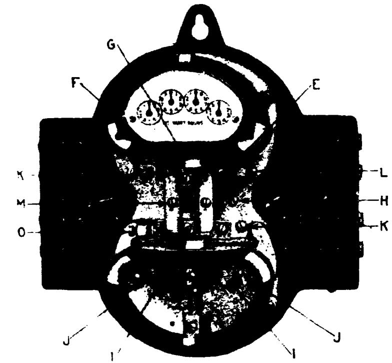


FIG. 411.—Duncan Model M2P polyphase watt-hour meter: L & O—light-load adjustment screws, E—upper light-load adjustment clamp screw, KK—balance adjustment clamp screws, H—balance adjustment screw, F—full-load adjustment clamp screw, G—full-load adjustment screw, JJ—inductive load adjustment clamp screws for lower element, II—inductive load adjustment for lower element, M—holding screw for dowelled full-load adjustment screw plate.

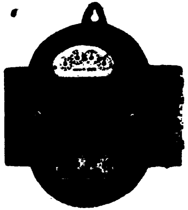


FIG. 412.—Duncan Model M2P Polyphase Induction Watthour Meter.

Data from 1923 edition of Handbook for Electrical Metermen

The methods of adjustment are exactly the same, except that a balancing adjustment is added, in order that the torques of the upper and lower elements may be exactly equalised. This is accomplished through the use of an eccentric, which raises the upper current electromagnet. This adjustment is carefully set at the factory, and seldom requires attention.

The explanatory view of the Model M2P, shown in figure 411, clearly indicates the various adjusting devices. The rotating element weighs but 21 grams, and the shaft is short, and therefore rigid. With the current coils in series, and the potential coils in parallel, on a single-phase source, the torque is approximately 75 millimeter grams, thus giving a ratio of torque to weight of about 3.5 to 1.

The M2P is made self-contained up to 600 volts, and 100 amperes, and can be supplied with either metal or glass covers. The terminal chambers at either side of the meter are filled with a fire- and moisture-proof compound.

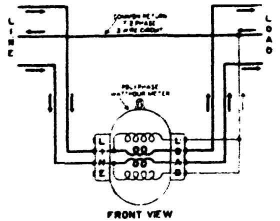


FIG. 413.—Connections of 3-phase, 3-wire, and 2-phase, 3-wire Duncan Model M2P polyphase watthour meter, 100 amperes and less, 600 volts and less.

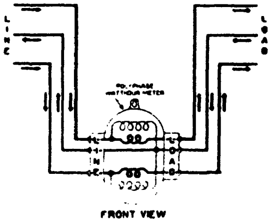


FIG. 414.—Connections of 3-phase, 3-wire Duncan Model M2P polyphase watthour meter with third wire through. This is supplied only on special order.

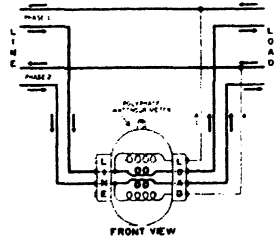


FIG. 415.—Connections of 2-phase, 4-wire Duncan Model M2P polyphase watthour meter, 100 amperes and less, 600 volts and less.

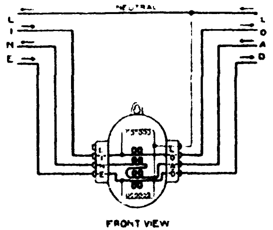


FIG. 416.—Connections of 3-phase, 4-wire Duncan Model M2P polyphase watthour meter, 50 amperes and less, 600 volts and less.

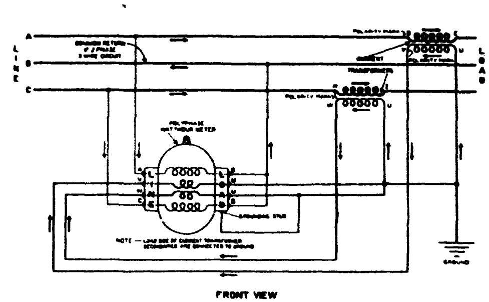


FIG. 417.—Connections of 3-phase, 3-wire, and 2-phase, 3-wire Duncan Model M2P polyphase watthour meter, with current transformers, 150 amperes and above, 600 volts and less.

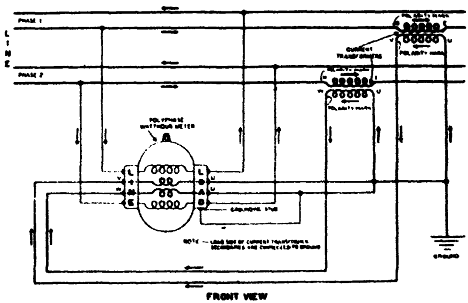


FIG. 418.—Connections of 2-phase, 4-wire Duncan Model M2P polyphase watt hour meter, with current transformers, 150 amperes and above, 600 volts and less

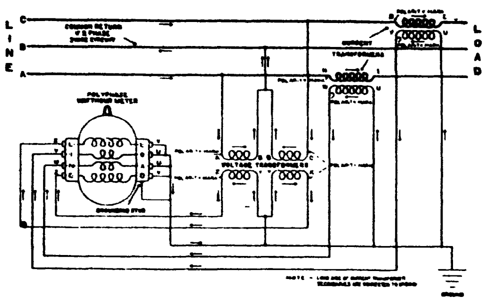


FIG. 419.—Connections of 3-phase, 3-wire, and 2-phase, 3-wire Duncan Model M2P polyphase watthour meter, with current and voltage transformers, all ampere ratings, 650 volts and above.

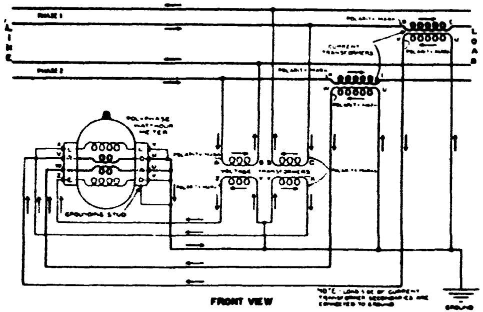


FIG. 420.—Connections of 2-phase, 4-wire Duncan Model M2P polyphase watthour meter, with current and voltage transformers, all ampere ratings, 650 volts and above.

Models M2S and M2PS Induction Switchboard-type Meters.—The mechanisms of Model M2S (single-phase) and M2PS (polyphase) switchboard-type alternating-current watthour meters are the same as the Model M2 and M2P service-type meters. The M2S

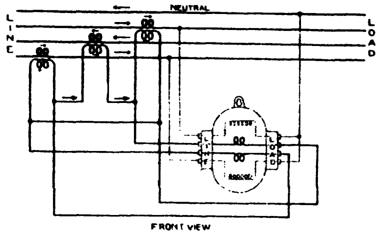


FIG. 421.—Connections of 3-phase, 4-wire Duncan Model M2P polyphase watthour meter, with current transformers, 75 amperes and above, 600 volts and less.

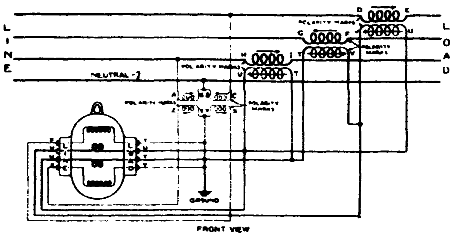


FIG. 422.—Connections of 3-phase, 4-wire Duncan Model M2P polyphase watthour meter, with current and voltage transformers, all ampere ratings, 650 volts and above.

and M2PS are provided with glass covers, and in addition all exposed metal parts are either japanned or have surfaces of highly polished nickel. (Figs. 423 and 424.)

The M2A (single-phase) and the M2PA (polyphase) have the same meter elements as the M2S and the M2PS, but are designed to meet the demand for less costly switchboard equipment. The covers are of pressed glass and the finish is in japan and white nickel. (Figs. 425 and 426.)

Data from 1923 edition of Handbook for Electrical Metermen

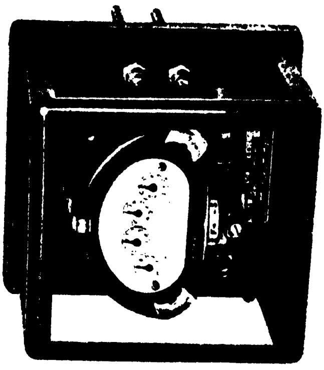


FIG. 423.—Duncan Model M2S Watthour Meter.

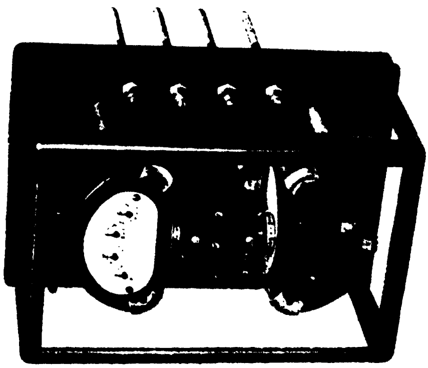


FIG. 424.—Duncan Model M2PS Polyphase Watthour Meter.

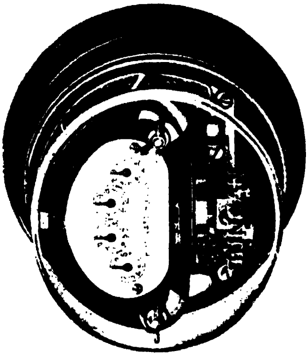


FIG. 425.—Duncan Model M2A Switchboard-type Single-phase Watthour Meter.

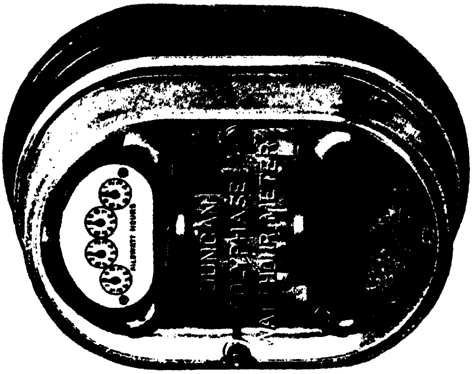


FIG. 426.—Duncan Model M2PA Switchboard-type Polyphase Watthour Meter.

GENERAL ELECTRIC WATTHOUR METERS

DESCRIPTIONS OF RECENT TYPES OF DIRECT-CURRENT WATTHOUR METERS.—The "Thomson Recording Wattmeters" of the types already referred to were superseded in 1904 by the Type C Thomson watthour meters, which, while based on the same fundamental principles, are essentially different in details of construction (Fig. 461).

Construction Features of Later Types.—Thomson direct-current watthour meters of Types C, C-5, C-6, C-7, C-9, CP, CP-2, CP-3, CP-4, CQ-2, CR, CS, CS-2, CS-3, CS-4, CB, CB-2, CB-3, CB-4, CB-5, G-2 and G-3 comprise those meters with spherical armatures.

Of these types the C-6, C-7, C-9, CP-4, CS, CS-3, CS-4, CB-5, and G-3 are the present standard direct-current watthour meters, the other types having been superseded. These meters use the spherical eight-coil armature, wound on a pressed paper core. The CS, CS-3, CS-4 and G-3 have two armatures mounted on one shaft. All armatures are wound with film-coated wire and after completion are protected by a coating of insulating paint baked on. The magnets, four in number, are arranged in pairs, which are astatically mounted on a rigid shoe.

Bearings.—The jewels are made of Ceylon sapphires for the lower ratings up to 50 kilowatts, and cupped diamonds are used in all direct-current meters of 50 kilowatts rating and over. The pivots, which are removable, are made from steel wire and have spherical tips.

Register.—The registers are all of the four-dial type (Fig. 462), reading directly in kilowatthours, except in a few of the higher ratings in which a register constant of 10, 100 or 1000 is used, as indicated on the register face. The register ratio is stamped on the back plate of the register.

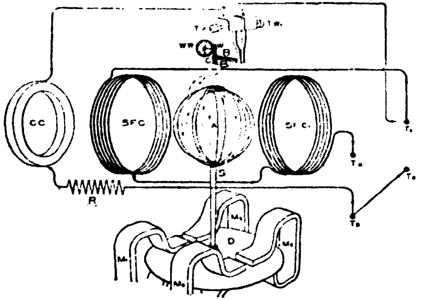


FIG. 461.—Diagram of Thomson, Type C, Watthour Meter. A, Armature; BB, Brushes; C, Commutator; CC, Friction Compensation Coil; D, Disk; M_1, M_2, M_3, M_4, Drag Magnets; S, Shaft; SFC Series Field Coils; T_1, T_2, T_3, T_4, Terminals; TW, Tension Weights for Brushes; W, Worm; WW, Worm Wheel.

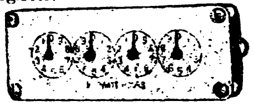


FIG. 462.—Register, Four-dial Type.

The ratio of the worm gear in all cases being 100:1, from the above the following formula is derived: Test constant × 100 × register ratio = watthours corresponding to one revolution of the most rapidly moving dial pointer.

The test constant is marked on the rotating element.

The watthour constant and test constant are identical.

The gear ratio is equal to the register ratio × 100.

Later Form Letters.—An explanation of the significance of the letters used in designating these types of Thomson direct-current watthour meters is given as follows:

C—House service type, rating 5 to 600 amp. 2-wire, and 5 to 300 amp. 3-wire, voltages up to 800 volts.
C-5—Essentially the same as C-6, but back connected and in same ratings as Types C-6 and C-7.
C-6—Superseded Type C in ratings up to 250 volts, inclusive.
C-7—Superseded Type C in ratings above 250 volts.
C-9—Superseded Type C-5, with omission of supporting lugs and altered potential stud arrangement.
CP—Prepayment type, used with separate prepayment device.
CP-2—Prepayment type in combination with C-6 watthour meter.
CP-3—Supersedes Type CP-2 with changed mechanical details.
CP-4—Supersedes Type CP-3 and is the same, except operating knob details, and slight changes.
CQ—House service type, with four-pole armature.
CQ-2—Same as Type CQ, except back connected.
CR—Similar to Types C-6 and C-7, except for slight changes in mechanical details.
CS—Astatic switchboard type.
CS-2—Same as Type CS, except that it is front connected.
CS-3—Similar to Type CS, but front connected.
CS-4—Same as Type CS-3, but back connected.
CB—Portable test meter with C-6 characteristics.
CB-2—Same as Type CB, except for a few mechanical improvements.
CB-3—Same as Type CB-2, except for a few mechanical improvements.
CB-4—Same as Type CB-3, but with some electrical differences; i.e., lower temperature coefficient of potential circuit and damping disk.

CB-5—Same as Type CB-4, but with heating connections omitted. Also, the low-rating meter is equipped with a commutating switch for series-parallel connection of current coils.

G-2—Astatic switchboard type, similar to Type CS, except that current coils are bus-bar type instead of circular.

G-3—Same as Type G-2, except that the cover consists of two parts, a metal sub-base and glass cover.

Type C Meters.—The Type C Thomson watthour meter was designed for house service for use on direct-current, two- and three-wire circuits, in ratings of 5, 10, 15, 25, 50, 75, 100, 150, 300 and 600 amperes, 100 to 800 volts, two-wire; and 5 to 300 amperes in like steps for 200 to 800 volts, three-wire. This type was in production from July, 1904 to November, 1905.

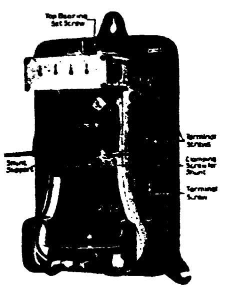


FIG. 463.—Internal View of Thomson, Type C-6 Direct-current Watthour Meter.

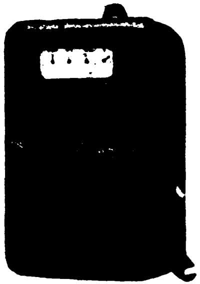


FIG. 464.—External View of Thomson, Type C-7 Direct-current Watthour Meter.

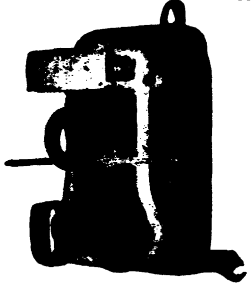


FIG. 465.—Internal View of Thomson, Type C-7 Direct-current Watthour Meter.

For meters up to 250 volts, the resistance was wound on a tube and mounted inside on the back of the meter. For meters above 250 volts up to and including 600 volts, the resistance was wound on a tube and mounted in an external cage on the meter back. For meters above 600 volts the resistance was wound on tubes and mounted in a separate box. The finish of the meter was dull black japan. The meter when required was furnished with glass cover. These meters were side connected.

Type C-6 and Type C-7 Meters.—The Type C Thomson watthour meters, in ratings up to 250 volts, have been superseded by the Type C-6. In ratings above 250 volts they have been superseded by the Type C-7. The Types C-6 and C-7 watthour meters have been in production since November, 1905. They are built in the same current ratings as the Type C, the Type C-7 meter being built for use on two-wire circuits only. The Type C-6 meter is furnished with the combined shunt and resistance, and with the Type C-7 meter the separate shunt field coil is used.

For meters up to 600 volts the resistance is wound upon tubes and mounted in an external cage upon the meter back. For meters above 600 volts, the resistance is mounted in a separate box. The finish is dull black japan. When so desired moulded glass covers can be furnished (Fig. 463, 464 and 465).

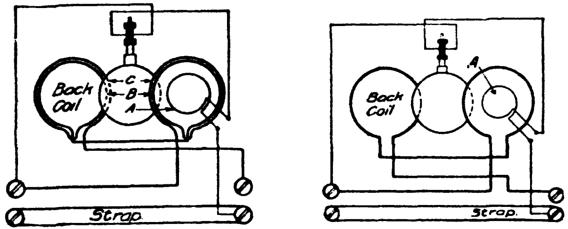
The leading-in wires enter into binding posts located at the sides of the meter.

Type C-5 and Type C-9 Meters.—The Type C-5 Thomson watthour meter was essentially the Type C-6, but back connected. It was built in similar ratings as the Types C-6 and C-7. Meters up to 250 volts were equipped with combined shunts and resistances; above this voltage the resistance was wound on tubes and mounted in a separate box.

The C-5 meter was finished in dull black japan and was furnished with moulded glass covers whenever desired. It was superseded by the present Type C-9. The difference between Types C-5 and C-9 watthour meters lies in the omission of supporting lugs on the Type C-9 meter and the vertical arrangement of the potential studs Type C-9 has been in production from November, 1905.

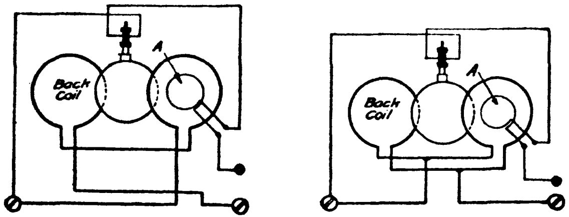
General Notes.—Two-hour overload capacity of 50 per cent of the full-load rating of these watthour meters is allowed.

Registers are all direct reading, except where a register constant is marked on a register. The only register constants used on registers are 10 and 100. The first dial reads directly in kilowatthours when the register constant is unity, each division being equal to one kilowatthour.



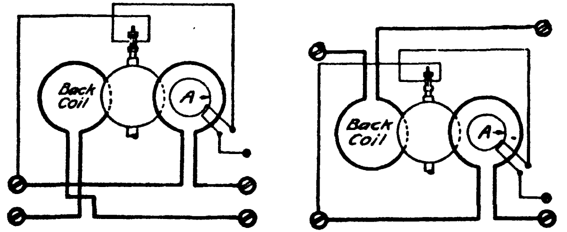
5-15 Ampere, 100-250 Volt, 2-wire.

25-50 Ampere, 100-250 Volt, 2-wire.



75-300 Ampere, 100-250 Volt, 2-wire.

600 Ampere, 100-250 Volt, 2-wire.



5-50 Ampere, 200-500 Volt, 3-wire.

75-300 Ampere, 200-500 Volt, 3-wire.

FIG. 467.—Diagrams of Internal Connections of Thomson, Types C and C-6 Watthour Meters. Service Enters on the Left.

Types C-6, C-7 and C-9 Meters

Coil Construction Data.—The following figures apply only to the more recent types of direct-current watthour meters:

Resistance of shunt field coil, Type C meter	**66 ohms**
Resistance of armature, Type C meter	**823 "**
Series resistance, Type C meter	**1541 "**
Total resistance potential circuit, Type C meter	**2430 "**
Ampere-turns, series field, Type C meter	**300**
Resistance of armature, Type C-6 meter	**930 ohms**
Number of effective turns in shunt field coil, Type C-6 meter	**800 to 2000**
Shunt field coil, Type C-7 meter	**1200 turns**
Resistance shunt field coil	**300 ohms**

Data for the Type C-6 are the same as for Type C-5 and C-9.

Types CP, CP-2, CP-3 and CP-4, Prepayment Meters.—The Type CP Thomson prepayment watthour meter is similar to the Type C-6, except in the number of terminals and a contact-making register. It was built in ratings of 3, 5, 10, 15 and 25 amperes, 100 to 250 volts, two-wire, and 200 to 250 volts three-wire. It was used in connection with a separate prepayment device.

The Type CP-2 Thomson prepayment watthour meter was a combination of the prepayment mechanism of the separate prepayment attachment and the Type C-6 watthour meter. This type of meter was built in ratings similar to the Type CP prepayment watthour meter and was adapted for either a 10-cent or 25-cent coin. The finish was similar to the Type C-6.

The Type CP-3 Thomson prepayment watthour meter superseded the Type CP-2. The principle of operation of the CP-3 was similar to the CP-2 but they differed greatly in mechanical details, changes having been made to provide greater reliability and convenience.

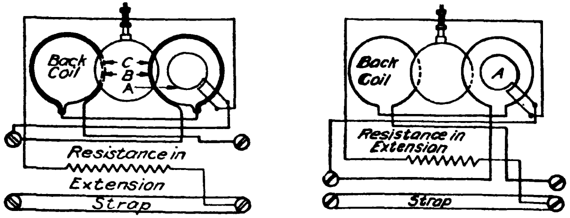
The Type CP-4 Thomson prepayment watthour meter supersedes the Type CP-3, and is the same electrically and mechanically, except that the operating knob is fastened in the cover and operates the prepayment mechanism through a driving dog, thus preventing any injury to the mechanism by strains on the knob. (Fig. 470.)

Types CQ and CQ-2 Meters (Four-Pole Type).—The Type CQ Thomson watthour meter, designed for house service, direct-current, is built in ratings of 50, 75, 100, 200 and 400 amperes, up to 800 volts, two-wire; and 50, 75, 100 and 200 amperes, 200 to 800 volts, three-wire (Fig. 474). This meter was produced in May, 1909.

The meter has a four-pole armature construction and the field coils are formed in quadrants surrounding the four-pole armature as completely as possible; this construction minimizes the effect of stray fields (Fig. 471). For watthour meters up to 300 volts, the resistance is wound upon tubes and mounted in an external cage upon the meter back. Above 300 volts, the resistance is wound on tubes and mounted in a separate box.

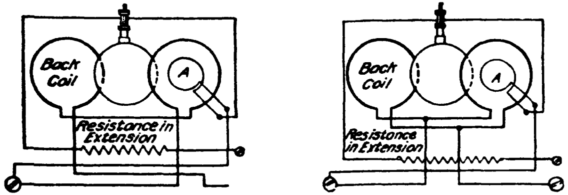
The leading-in wires enter binding posts located at the side of the meter.

The Type CQ-2 Thomson watthour meter differs from the Type CQ only in that it is back connected. It was first produced in November, 1909.



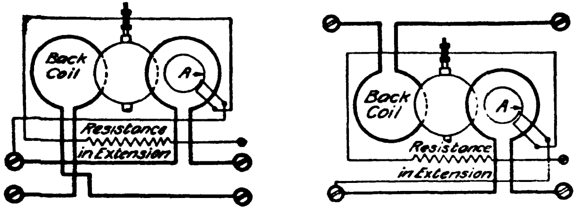
5-15 Ampere, 250-800 Volt, 2-wire.

25-50 Ampere, 250-800 Volt, 2-wire.



75-300 Ampere, 250-800 Volt, 2-wire.

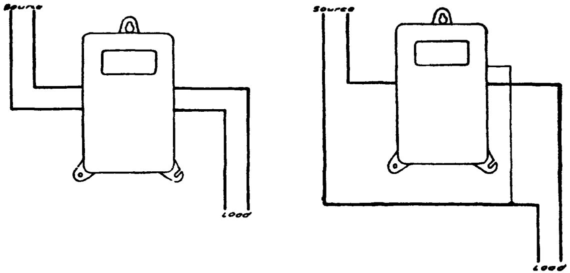
600 Ampere, 250-800 Volt, 2-wire.



5-50 Ampere, 250-800 Volt, 3-wire.

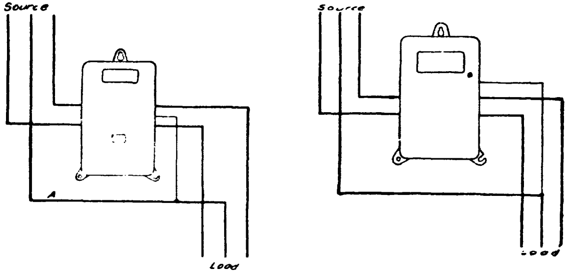
75-300 Ampere, 501-800 Volt, 3-wire.

FIG. 468.—Diagrams of Internal Connections of Thomson, Types C and C-7 Watthour Meters. Service Enters on the Left.



Two-Wire. Type C-6, 5 to 50 Amperes, 106 to 120 Volts, 212 to 240 Volts. Type C-7, 5 to 25 Amperes, 500 to 600 Volts.

Two-Wire. Type C-6, 75 to 600 Amperes and Type CQ, 50 to 400 Amperes, 106 to 120 Volts, 212 to 240 Volts. Type C-7, 50 to 600 Amperes, 500 to 600 Volts.



Three-Wire. Type C-6, 5 to 50 Amperes, 212 to 240 Volts.

Three-Wire. Type C-6, 75 to 300 Amperes and Type CQ, 50 to 200 Amperes, 212 to 240 Volts.

FIG. 469.—External Connection Diagrams for Type C-6 Watthour Meters.

Types CS and CS-2 Meters.—The Type CS Thomson watthour meter designed for switchboard service, direct-current, is built in ratings of 50, 75, 100, 150, 200, 300, 400, 600, 800, 1200 and 1500 amperes, up to 800 volts, two- and three-wire (Fig. 475). It has been in production since November, 1907.

The meter has two spherical armatures mounted astatically on the same shaft The series field is constructed of copper punchings joined in such a way that the current divides and flows completely around and close to each armature so as to give a maximum influence of the magnetic flux. The resistance for all Type CS watthour

Data from 1923 edition of Handbook for Electrical Metermen

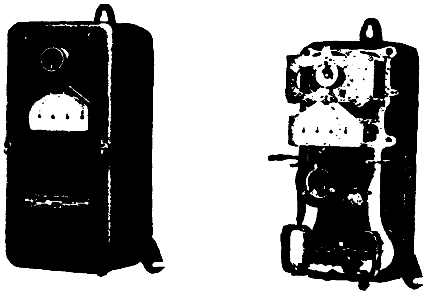


FIG. 470.—Thomson, Prepayment, Type CP-4 Watthour Meter.

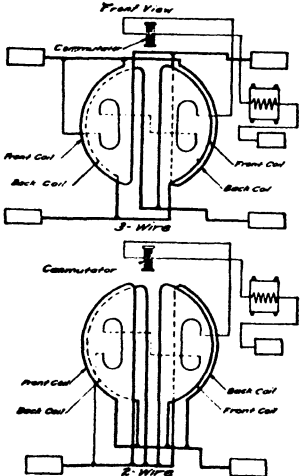


FIG. 473.—Internal Connections of Thomson Types CQ and CQ-2 Watthour Meters. Resistance for Type CQ Meters up to 300 Volts, 2-wire, and 600 Volts, 3-wire, mounted in a Cage upon the Meter Back. Resistance for Type CQ Meters above 300 Volts, 2-wire, and 600 Volts, 3-wire, all Type CQ-2 Meters and Special Type CQ Meters mounted in a Separate Box.

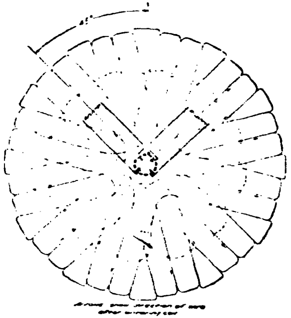


FIG. 471.—Four-pole Armature of Thomson, Type CQ Watthour Meter.

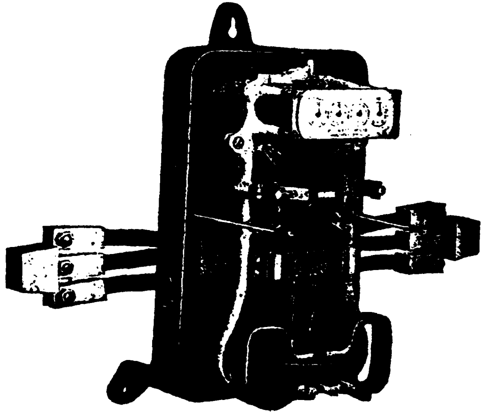


FIG. 474.—Thomson, Type CQ Watthour Meter.

meters is wound upon tubes and mounted in a separate box. The meter has a glass cover and is finished in dull black japan, the prominent internal parts being finished in polished brass.

The Type CS-2 Thomson watthour meter is the same as the CS, except that it is front connected, has a metal cover, and the internal parts are left unpolished (Fig. 476). It has been in production since August, 1910.

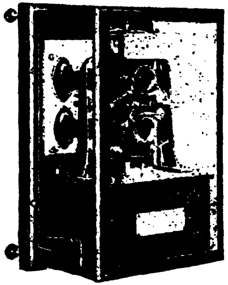


FIG. 475.—Type CS Watthour Meter.

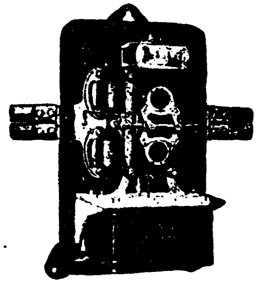


FIG. 476.—Type CS-2 Watthour Meter.

Type CS-3 and Type CS-4 Watthour Meters.—The Types CS-3 and CS-4 watthour meters are modifications of the Type CS double armature, astatic switchboard meter. They were placed in production in 1916, and differ from each other only in that the Type CS-4 is back connected.

The principal difference between the Types CS, CS-3 and CS-4 meters lies in the housing and in the omission of the magnet shield. A meter of lower manufacturing cost is thereby obtained. The retention of the astatic feature of the armatures and field coils insures immunity under conditions of uniform stray fields.

The base is of cast alloy, rectangular in shape. It is supported by three lugs, one at the top and two at the bottom. The terminals are located at the side, as in the Type C-6 meter.

The frame is of aluminum alloy, supported at the four corners and insulated from the base. This frame carries the entire electrical, damping and registering elements.

The field coils, of which there are four, are made from strip copper and arranged in two sets with the two armatures so as to secure the astatic effect.

The armatures are the same as used in the Type CS meter. They are mounted upon one shaft and are arranged to correspond with the astatic field construction.

The compensating, or light-load coil, is the same as used in the Type C-7. The adjustment is effected in the same way as in the

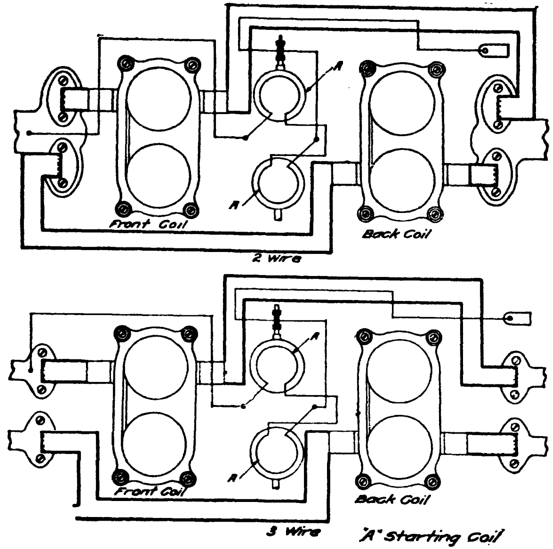


FIG. 477.—Internal Connections of Thomson, Type CS and CS-2 Watthour Meters. Service Enters on the Left for Two-wire Meters and for Three-wire Meters Enters Upper Left Hand and Lower Right Hand Terminals.

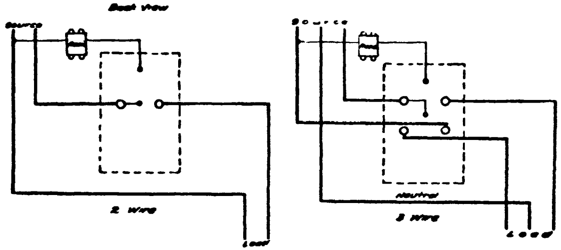


FIG. 478.—External Connections of Thomson Type CS Watthour Meters.

Type C-7 meter; that is, by swinging the coil up or down as may be required.

Additional resistance to that in the compensating coil is required in the potential circuit. This is wound on tubes and supported on brackets in a horizontal position just above the magnets in all meters for 250 volt circuits and less. For circuits above 250 volts, the resistance is mounted in a separate box.

The brushes, permanent magnets and register are the same as used on Type CS meters.

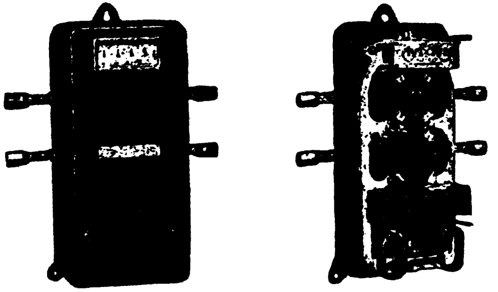


FIG 479.—Type CS-3 Watthour Meter.

Types CS-3 and CS-4 meters are built in ratings from 15 to 600 amperes, 110, 220 and 550 volts, two-wire, and from 15 to 400 amperes, 220 volts, three-wire.

Types G-2 and G-3 Meters (Large Capacity, Switchboard Pattern).—The Type G-2 Thomson watthour meter was designed for switchboard service upon direct-current, two- and three-wire circuits, and was put into production in May, 1908.

It is built in ratings of 2000, 3000, 4000, 6000, 8000, 10,000 and 15,000 amperes: up to 800 volts, two-wire, and 2000, 3000, 4000, and 6000 amperes, 200 to 800 volts, three-wire.

The resistance for all Type G-2 watthour meters is wound upon tubes and mounted in a separate box. This type of watthour meter uses the astatic armature of the spherical type and the shielded damping mechanism similar to the Type CS watthour meter. It has a rectangular glass cover and is finished in polished copper and brass. The cover is secured to the switchboard by four bolts.

The Type G-3 Thomson watthour meter, which supersedes the Type G-2, is similar in every respect except for a cover or case which consists of two parts, a metal sub-base which is bolted to the switchboard, and a glass cover which is fastened to this sub-base by means of screws. With this construction, the cover is removable from the front.

The Type G-3 has been in production from January, 1911, to date. In November, 1916, the resistance was placed inside of the meter cover.

DESCRIPTIONS OF THOMSON ALTERNATING-CURRENT, INDUCTION WATTHOUR METERS.—In the General Electric (Thomson) induction type of watthour meter for alternating-current circuits, there is the usual combination of current and potential elements, establishing a rotating field which induces currents in a movable closed secondary. As in all watthour meters, the speed must be proportional to the wattage. In order for this to hold true the combination of elements above referred to must produce a torque or turning moment directly proportional to the load or wattage. The rotating element, which is constructed of non-magnetic material, moves between the poles of permanent magnets which generate currents in it directly proportional to the speed.

Construction Features.—The arrangement of the parts and connections of the coils of the Type I induction meter are shown diagrammatically in Fig. 484, which is a rear view. The figure is lettered for reference.

D is an aluminum disc, mounted to rotate between the series and potential magnet poles, also between the poles of the permanent magnet brake.

SFC are the main series field coils wound in opposite directions on projecting iron cores. These coils produce the series field proportional to the current in the circuit.

IC is the impedance coil producing the field of the potential circuit proportional to the line voltage. This winding has a high reactance and is connected directly across the main circuit. The magnetic field produced lags nearly 90 degrees with respect to the voltage impressed.

PC is a phasing coil consisting of a closed secondary or lagging winding, which produces a sufficient additional field to establish the phase relation required.

AR is an adjustable resistance in series with the closed secondary winding to regulate the magnitude of the current.

LLA is the light-load adjustment, a closed secondary of one turn of copper placed around the core of the potential coil and arranged to produce the necessary unbalancing of the field of the potential coil to compensate for friction.

L is a lever provided for adjusting the position of the closed secondary LLA with respect to the iron core.

T_1, T_2, T_3, and T_4 are the main terminals for connecting the meter in circuit.

BB is the bus-bar.

Light-load Adjustment.—The induction watthour meter is provided with a light-load adjustment which can be used to correct for variations in local conditions. The device consists of a metal punching or sector, forming a closed secondary turn, placed in the path of the potential flux. Standing so that the device is brought directly between the observer and the shaft of the rotating element of the meter, motion of the sector toward the right increases the speed at light loads; moving it toward the left causes the meter to run more slowly at light loads and also tends to prevent creeping.

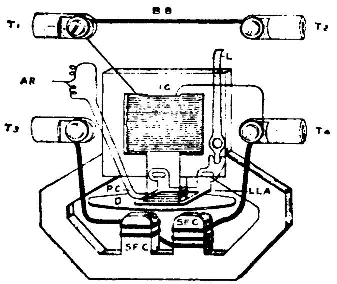


Fig. 484.—Internal Arrangement of Thomson, Type I, Induction Watthour Meter. (Rear View.)

If the sector is moved too far, so as to pass beyond the field of the electromagnet, its effects will be correspondingly diminished. The movement affects the light-load accuracy, having practically no effect on the full-load accuracy of the meter; hence, it is not necessary to recalibrate the watthour meter at full load unless a very large change is made in the light-load adjustment.

Creep Prevention.—Owing to its lightness, there may be a tendency under certain conditions for the rotating element of these watthour meters to creep on no load. even when the light-load adjustment is properly set. To counteract this in High Torque and earlier types, an iron wire is fastened to the disk adjacent to the hub. This wire should not be moved unless it is found that creeping exists. The wire should then be slightly inclined radially away from the shaft. Moving the wire toward the shaft will tend to make the meter run faster on light load. On High Torque watthour meters this iron wire is placed around the hub parallel with the disk and may be bent to or from the shaft.

The adjustment when properly made will not in any way interfere with the running of the watthour meter, but will prevent creeping on no load.

In the types I and D, the tendency to creep is counteracted by two small holes in the disk.

In all of the induction types the test constant is given in watthours. The register ratio is stamped on the back plate of the register. The gear ratio equals the register ratio times 100. The test constant is marked on the rotating element.

Form Letters of Induction Type Meters.—The following is given as an explanation of the significance of the letters used in designating these types of Thomson induction watthour meters. It should be noted that the I types include the single-phase forms, and that the D types include the universal polyphase forms.

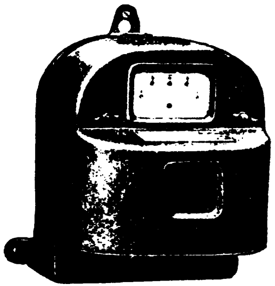


Fig. 485.—Thomson High-torque, Single-phase, Induction Watthour Meter.

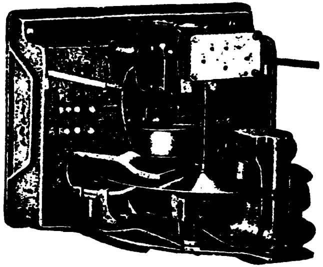


Fig. 486.—Internal View of Thomson Rectangular Pattern, Form DF2, Polyphase, Induction Watthour Meter.

High Torque—House service, single-phase type (Fig. 485). Superseded by Type I.
Type I —House service, single-phase type.
Type I-8 —Similar to Type I, except that terminals are in separate compartment.
Type IP —Prepayment watthour meter similar to the Type I, except in number of terminals and contact making register. It is accompanied by a separate prepayment device operated by the contact device in meter.
Type IP-2 —This is the prepayment device and watthour meter combined, being interconnected mechanically instead of electrically as in the Type IP.

Type IP-3 —Is a radical redesign of the IP-2 where the meter and prepayment mechanism are mounted in the same case.

Type IP-4 —Supersedes the Type IP-3 with changes in the operating knob and other minor mechanical details.

Type IP-5 —Embodies the I-14 element, the introduction of which brought about many changes in design to adapt the prepayment mechanism with the essential features of the I-14.

Type I-10 —Low-rating house service, single-phase type.

Type I-14 —Supersedes the Type, I, I-8 and I-10 for single-phase house service.

Type IS —Switchboard, single-phase type.

Type IS-2 —Same as IS, except in mechanical details and damping mechanism.

Type IS-3 —Same as IS-2 except that it has glass cover.

Type IS-4 —Switchboard, single-phase type. Smaller than Type IS-2, has Type I-14 element.

Type IS-5 —Same as Type IS-4 except removable terminal construction.

Type DF-2—Polyphase rectangular pattern. Superseded by Type D-3.

Type D-3 —House service, polyphase type.

Type D-4 —Similar to D-3, except separate terminal compartment.

Type D-6 —House service, polyphase type (Fig. 532). It is a combination of two Type I-14 meters in the same case.

Type D-7 —Same as Type D-6 except that it has glass cover.

Type DS-2—Switchboard, polyphase type, with cast metal cover.

Type DS-3—Same as DS-2, except that it has glass cover.

Type DS-4—Supersedes Type DS-2, with slight difference in location of electrical elements.

Type DS-5—Supersedes Type DS-3, with slight difference in location of electrical elements.

Type DS-6—Switchboard, polyphase type. Smaller than Type DS-4 and has Type I-14 elements.

Type DS-7—Same as Type DS-6 but with removable terminals.

Type IB —Portable rotating standard type, with characteristics similar to Type IS in some respects.

Type IB-2 —Supersedes Type IB, with changes in damping system.

Type IB-3 —Similar to Type IB-2 except that range was extended and details changed.

Type IB-4 —Similar to Type IB-3 except minor details.

Type IB-5 —A small light-weight rotating standard using the Type I-14 element for testing low rating alternating-current meters.

Type IB-6 —Similar to Type IB-5 in regards to element but is manufactured in larger ratings and has different binding post construction.

Type I Meters.—The Type I Thomson watthour meter was designed for house service on single-phase, two- or three-wire circuits. It was self-contained in ratings of 3, 5, 10, 15, 25, 50, 75, 100, 150, 200 and 300 amperes, 100 to 650 volts, 36 cycles and above, and 100 to 300 volts, 25 to 35 cycles for two-wire circuits; and 3, 5, 10, 15, 25, 50, 75, 100 and 150 amperes, 200 to 650 volts, 25 cycles and above, for three-wire circuits. For three-wire circuits above 150 amperes, and two-wire circuits above 300 amperes, current transformers were supplied (Fig. 487). It was produced in December, 1903.

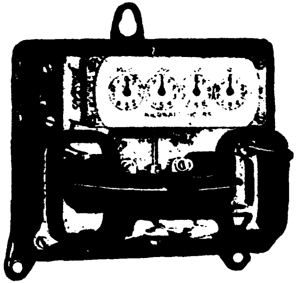


FIG. 487.—Internal View of Thomson, Type I, High-torque, Single-phase, Induction Watthour Meter.

This type of watthour meter was sometimes furnished double lagged for 60 cycles and higher frequency. By changing the connections inside of the meter, it may be used for either frequency for which it is rated. (Fig. 488).

This meter was finished in dull black japan, the cover being provided with glass windows for observing the operation of the rotating element and for reading the meter registers. When desired a moulded glass cover was furnished.

The leading-in wires enter the binding posts located at the sides of the meter.

Type I-8 Meters.—The Type I-8 Thomson watthour meter, like the Type I, was designed for house service, and is built in ratings of 3, 5, 10, 15, 25, 50 and 75 amperes, 100 to 650 volts, 25 cycles and above, for use on two- or three-wire single-phase circuits. It was produced in March, 1906.

This watthour meter is essentially the same as the Type I, except that the terminals are located in a separate compartment at the bottom of the watthour meter, permitting the connection to be made without removing the cover of the meter proper.

For gaining access to the jewel screw when the watthour meter is sealed, the meter cover is drilled directly below the jewel screw and by removing the terminal cover the jewel may be readily removed for inspection or replacement. Replacing the terminal cover prevents further access to the jewel screw.

This watthour meter element is electrically identical with the Type I, and the same data apply.

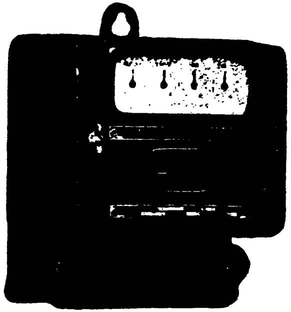
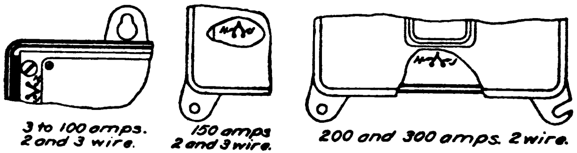


FIG. 490.—External View of Thomson, Type I-8, High-torque, Single-phase, Induction Watthour Meter.



3 to 100 amps. 2 and 3 wire.

150 amps 2 and 3 wire.

200 and 300 amps. 2 wire.

FIG. 491.—Connections of Thomson, Type I, Single-phase, Induction, House Pattern Watthour Meters, Showing Method of Making Connections for Testing upon Separate Potential.

If it is desired to test with separate potential connections, unsolder H and J. Connect J to one side of the source. In two-wire meters and in three-wire 150 Amp. meters connect the opposite side of source to upper right-hand terminal. In three-wire meters 3 to 100 Amps., connect opposite side of source to central right-hand terminal.

Connections of Thomson Types I and I-8 Watthour Meters for Double Lag Adjustment and Separate Potential Testing.

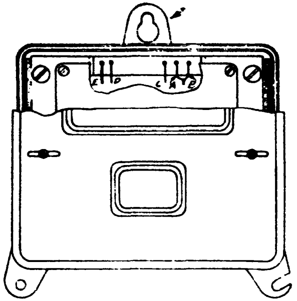


FIG. 488.—Connections of Thomson, Type I, Single-phase, Induction, House Pattern Watthour Meters, Showing Method of Making Connections for Double Lag Adjustment.

This sketch shows the connections made for the higher of the two frequencies. If it is desired to run the meter on a lower frequency, disconnect the wire A from B and solder A to C. Make a soldered connection between D and E. No other change is required except that it may be necessary to readjust on light load.

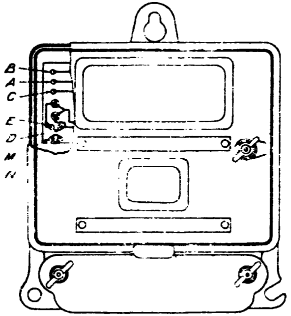


FIG. 489.—Connections of Potential Circuit of Thomson, Type I-8, Single-phase Induction, House Pattern Watthour Meters, Showing Method of Making Connections for Double Lag Adjustment.

For lower frequencies A must be soldered to C and D to E. For higher frequencies A must be soldered to B and D and E left open circuited.

Testing Loop: If it is desired to test meter on separate potential circuit, M and N should be opened and line connection made to N.

Data from 1923 edition of Handbook for Electrical Metermen

External Connection Diagrams

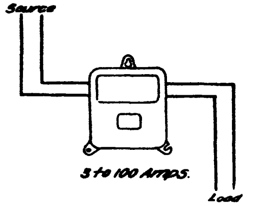


FIG. 492.—External Connections of Thomson, Type I, Single-phase, Induction Watthour Meters, 3 to 100 Amps., up to 650 Volts, 25-140 Cycles, 2-wire, without Instrument Transformers.

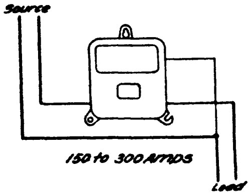


FIG. 493.—External Connections of Thomson, Type I, Single-phase, Induction Watthour Meters, 150 to 300 Amps., up to 650 Volts, 25-140 Cycles, 2-wire, without Instrument Transformers.

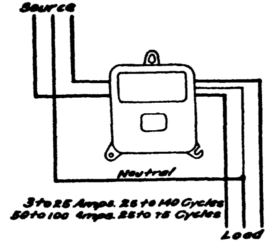

Source
Neutral
3 to 25 Amps. 25 to 140 Cycles
50 to 100 Amps. 25 to 75 Cycles
Load

FIG. 494.—External Connections of Thomson, Type I, Single-phase, Induction Watthour Meters, 3 to 25 Amps., 200-650 Volts, 25-140 Cycles, 3-wire, without Instrument Transformers, Front View. 50 to 100 Amps., 200-650 Volts, 25-75 Cycles, 3-wire, without Instrument Transformers.

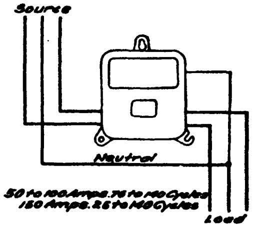


FIG. 495.—External Connections of Thomson, Type I, Single-phase, Induction Watthour Meters, 50 to 100 Amps., 200-650 Volts, 76-140 Cycles, 3-wire, without Instrument Transformers.

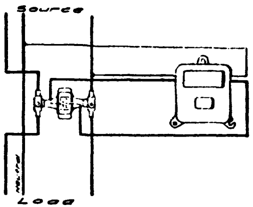


FIG. 496.—External Connections of Thomson, Type I, Single-phase, Induction Watthour Meter with Form DM-16 Current Transformer for Three-wire Service. Above 150 Amps., 3-wire, 200-240 Volts, 25-140 Cycles.

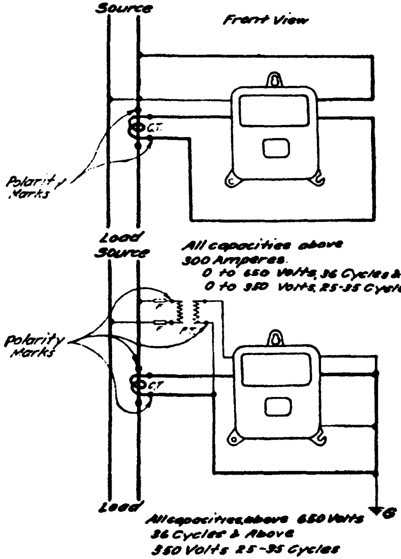

Source
Front View
C.T.
Polarity Marks
Load
Source
All capacities above 300 Amperes.
0 to 650 Volts, 36 Cycles & above
0 to 350 Volts, 25-35 Cycles
F
F
P.T.
Polarity Marks
C.T.
Load
G
All capacities above 650 Volts 36 Cycles & Above
350 Volts 25-35 Cycles

FIG. 497.—External Connections of Thomson, Type I, Single-phase, Induction Watthour Meters, with Instrument Transformers.

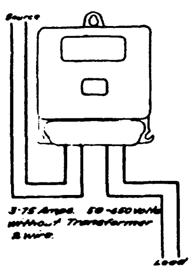


FIG. 498.—External Connections of Thomson, Type I-8, Single-phase Watthour Meter, 3-75 Amps., up to 650 Volts, 2-wire, 25-140 Cycles, without Instrument Transformers.

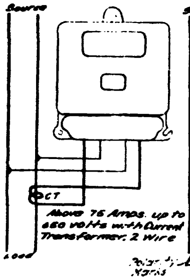


FIG. 499.—External Connections of Thomson, Type I-8, Single-phase Watthour Meter, above 75 Amps., up to 650 Volts, 2-wire, 25-140 Cycles, with Current Transformer.

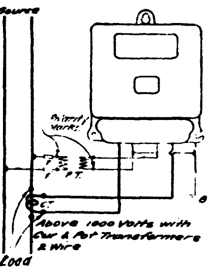


FIG. 500.—External Connections of Thomson, Type I-8 Single-phase Watthour Meter, above 1000 Volts, 2-wire, 25-140 Cycles, with Current and Potential Transformers.

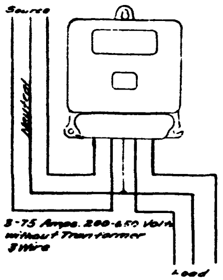


FIG. 501.—External Connections of Thomson, Type I-8, Single-phase Watthour Meter, 3-75 Amps., 200-650 Volts, 3-wire, 25-140 Cycles, without Instrument Transformers.

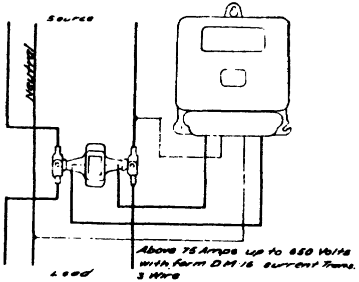


FIG. 502.—External Connections of Thomson, Type I-8, Single-phase, Watthour Meter, above 75 Amps., up to 650 Volts, 3-wire, 25-140 Cycles with Form DM-16 Current Transformers.

Type I-10 Meters.—The Type I-10 Thomson watthour meter was designed to meet the demand for a low-rating, single-phase, two- or three-wire house meter. It was produced in 1910.

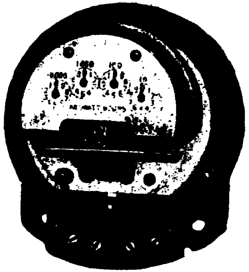


FIG. 503.—Internal View of Thomson, Type I-10, Single-phase Induction Watthour Meter.

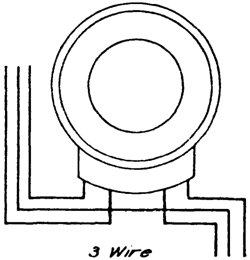


FIG. 504.—External Connections of Thomson, Type I-10, Single-phase Induction Watthour Meter, 5-10 Amps., 200-240 Volts, 3-wire. For 100-240 Volt, 2-wire Meter, Omit Neutral Wire from Diagram.

This type of watthour meter is different in construction and appearance from any type of induction watthour meter previously put on the market by the General Electric Company (Fig. 503) although the electrical properties are little different from the Type I, watthour meter.

The full-load adjustment is accomplished by shunting the flux of the magnet about the disk instead of moving the magnets, as in the

Type I. The register face of the early form of Type I-10 meter has three dials, but 4-dial registers were used on later meters. This watthour meter is circular in form, the cover screws into place, similar to the top of a fruit jar, and it has a moulded terminal block at the bottom of the meter base into which the leading-in wires pass. The jewel and pivot are removable and the friction compensation is adjustable. The dials read in kilowatthours, and the register face is of dull finish porcelain. The meter back and cover are finished in dull black japan.

Type I-14 Meters or Type K-5 Meters.—The Types I-14 and K-5 are identical. The former is manufactured at the Lynn Works, while the latter was manufactured at the Fort Wayne Works of the General Electric Company until February, 1916.

The Type I-14, (or Fort Wayne Type K-5) watthour meter, was designed to meet the demand for a low-price, single-phase induction meter for house service, that could be supplied in a complete line of ratings, inasmuch as the Type I-10 and K-4 were adapted only for the low ratings. It was produced in January, 1914.

Construction Features.—While in external appearance this meter resembles somewhat the Type I-10, its design and construction are radically different from that of any meter heretofore marketed by the General Electric Company. (See Fig. 505.)

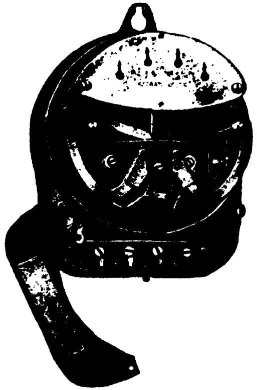


FIG. 505.—Internal View of Type I-14, Single-phase Watthour Meter. 5-25 Amperes.

The base is a hollow iron casting and supports all constituent parts of the meter. The electrical element is mounted on the inside while the registering, damping and moving elements are mounted on the outer or front side. The opening in the back is closed by a punched iron plate secured by two screws from the front and accessible only when the cover is removed.

It is equipped with micrometer full- and light-load adjustments The terminals are mounted in a separate compartment and sealed separately. The cover is held by two sealing pins and wing nuts. This meter is built self-contained in a complete line of ratings from 5 to 300 amperes, two-wire and 150 amperes three-wire, 25 to 140 cycles, 100 to 600 volts.

Types IP, IP-2, IP-3, IP-4 and IP-5 Prepayment Meters.—The Type IP prepayment watthour meter consisted of a Type I watthour meter with two extra terminals and a contact device in the register and a separate prepayment device of the well-known "Wood" construction. The prepayment mechanism was tripped electrically by means of an electromagnet, operated by the contact device in the register of the meter. With this design the meter could be installed in one part of the house and the prepayment device in another location more convenient for the customer. This type of watthour meter was built in ratings of 3, 5, 10, 15, and 25 amperes, 100 to 250 volts, 25 cycles and above, for two-wire circuits, and 200 to 250 volts, 25 cycles and above for three-wire circuits, and was adapted for either a ten- or a twenty-five-cent coin.

This meter was furnished in black japan, the cover, as the other forms of induction watthour meters, being provided with register and disk windows.

The Type IP-2 Thomson prepayment watthour meter was a combination of the separate prepayment attachment and the Type I watthour meter, the former being mounted on the top of the watthour meter proper, the gearing and actuating mechanism being directly connected to the recording mechanism of the meter.

This type of meter was built in the same ratings as the Type IP and was produced in September, 1905.

The Type IP-3 Thomson prepayment watthour meter was a radical redesign, and superseded the Type IP-2 watthour meter. The same improved design and construction of mechanism are incorporated in the CP-3 prepayment meter.

The watthour meter and prepayment mechanism are housed in the same case, and are accessible for adjustment by removing the meter cover. The coin box may be emptied by the collector without removing the meter cover, and, conversely, removal of the meter cover does not permit of access to the coin box.

For convenience in reading the register and noting the number of coins to the customer's credit, the coin register and watthour meter register faces are combined, the pointer and scale indicating the coins to credit being directly above the dials of the meter register.

Like the IP-2 meter, the Type IP-3 was built in ratings of 3, 5, 10, 15, and 25 amperes, 100 to 250 volts, 25 cycles and above, for two-wire circuits, and 200 to 250 volts for three-wire circuits. It was produced in September, 1908.

The Type IP-4 Thomson prepayment watthour meter supersedes the Type IP-3, and is the same throughout, except that the operating knob is fastened in the cover and operates the prepayment mechanism through a driving dog, thus preventing injury of the mechanism by any strain on the knob (Fig. 515).

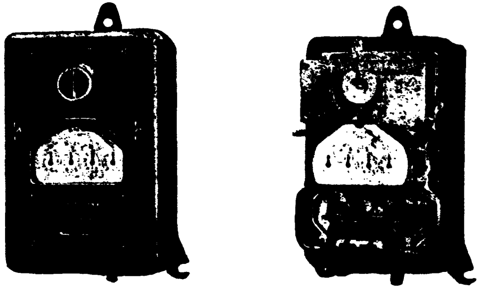


FIG. 515.—External and Internal Views of Thomson, Type IP-4, Prepayment, Single-phase, Induction Watthour Meter.

The Type IP-4 meter element is electrically identical with the Type I, and same data applies. It was produced in October, 1908.

The type IP-5 prepayment meter operates on the same principle as the Type IP-4, although the general design and relation of parts of the former are quite different from the IP-4 in order to combine the standard electrical element of the Type I-14 meter with the prepayment mechanism. The crediting and switching mechanisms are mounted at the top of the meter and the coin box in a compartment at the bottom. The terminals are in a separately sealed compartment at the top, the line wires entering and leaving at the side. The back cover plate, similar to that in the standard type I-14, closes the element chamber. Removal of this plate exposes the entire electrical element. The supporting screws are sealed.

The coin chute conducts the coin down through the meter chamber into the coin receptacle. Removing the meter cover provides access to the meter chamber only, and does not open the coin receptacle. The latter is securely locked in place and when removed does not afford access to the meter chamber.

The Type IP-5 meter is made in ratings 5 to 15 amperes, 110 to 220 volts, for either two- or three-wire service. This type was produced in November, 1916.

Types IS, IS-2, IS-3, IS-4 and IS-5 Meters (Switchboard Pattern).—The Type IS Thomson watthour meter was designed for switchboard use on single-phase, two- and three-wire circuits.

In this type the drag magnets are not movable. Full-load adjustment is accomplished by shunting more or less of the magnetic lines of force. In order to do this, the meter has four angle irons fastened at the front of the magnets. Moving these irons nearer together will make the meter run faster, while moving them apart will make it run more slowly.

A small rectangular conductor located below the potential coil provides for light-load adjustment. The movement of this conductor is controlled by a lever at the upper left-hand side of the meter. To change the adjustment, loosen the screw and move the lever to the right or left, as required. Moving the lever to the right increases the speed on light load, while a movement to the left decreases it. This type was produced in October, 1903.

The Types IS-2 and IS-3 Thomson watthour meter superseded the Type IS watthour meter.

The Type IS-2, produced in May, 1905, is the same as the Type IS, with the exception of changes in the mechanical construction and damping mechanism. The damping mechanism is identical with that of the Type I watthour meter, and the moving element is the same as the Type IS. The terminals and frames have been modified. The cover is of cast iron.

The Type IS-3 meter is identical with the IS-2 except for the cover, which is of glass (Fig. 520). This type was produced in January, 1906.

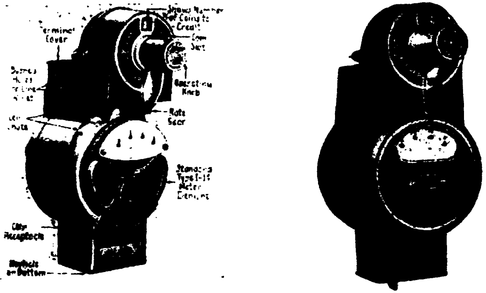


FIG. 517.—Thomson Single-phase Prepayment Watthour Meter, Type IP-5.

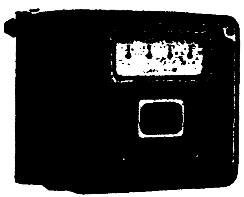


FIG. 519.—Thomson, Type IS-2, Single-phase, Induction Watthour Meter.

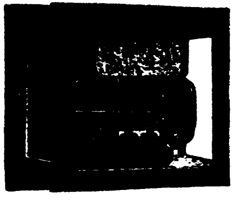


FIG. 520.—Thomson, Type IS-3, Single-phase, Induction Watthour Meter.

The Type IS-4 single-phase watthour meter is designed for switchboard use. The motor element, damping system and adjustments are the same as those of the I-14 meter. The register is the same as was used on the type IS-2 meter and the external appearance and finish are very similar. This meter is, however, somewhat smaller than the type IS-2.

It is built self-contained in ratings 5, 10, 15, 25, 50, 75, 100, 150 amperes, 110, 220, 440, 550 volts, 25, 40, 50, 60, 125, 133 cycles. This type was produced in 1915.

The Type IS-5 meter is identical with IS-4 except for the cover, which is of glass. This type was produced in 1915.

Types D-3, D-4, D-6 and D-7 Polyphase Meters.—The Type D-3 Thomson watthour meter is designed for house service upon two-phase, three-phase and monocyclic circuits of balanced or unbalanced loads. It is built self-contained, in ratings of 3, 5, 10, 15, 25, 50, 75, 100, and 150 amperes, up to 650 volts, 25 cycles and above, for use upon four-wire, two-phase; three-wire, two- and three-phase; and monocyclic circuits, and in ratings of 3, 5, 10, 15, 25, 50 and 75 amperes, up to 650 volts, 25 cycles and above, for use upon four-wire, three-phase circuits.

As in the case of Type I watthour meters, this type of meter may be used for switchboard service with good results, where a back-connected meter is not desired.

This meter is finished in dull black japan, the cover being provided with glass windows for observing the operation of the moving element and for reading the meter dials.

The leading-in wires enter binding posts located at the sides of the meter. (Fig. 522.)

The Type D-4 Thomson watthour meter, like the Type D-3, is designed for house service and is built in ratings of 3, 5, 10, 15, 25, 50 and 75 amperes, 100 to 650 volts, 25 cycles and above, for use upon three-wire, two- and three-phase, and four-wire, two- and three-phase circuits. This type of watthour meter is in general similar to the Type D-3 except that the terminals are located in a separate compartment at either side of the meter back, permitting the connection to be made without removing the cover of the meter proper (Fig. 521). It was produced in March, 1906.

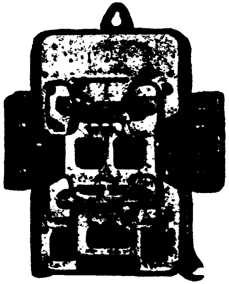


FIG. 521.—Internal View of Thomson Type D-4, Polyphase Induction Watthour Meter.

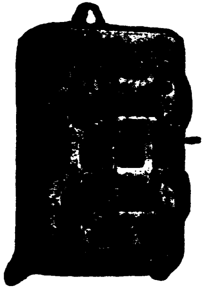


FIG. 522.—Internal View of Thomson Type D-3 Polyphase Induction Watthour Meter.

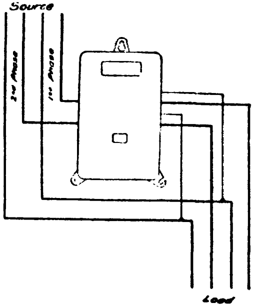


FIG. 523.—External Connections of Thomson, Type D-3, Polyphase, Induction Watthour Meters, 3-150 Amps., up to 650 Volts, 25 Cycles and above; 4-wire, 2-phase Circuits without Instrument Transformers. Front View.

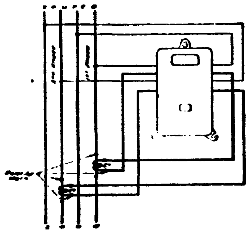


FIG. 524.—External Connections of Thomson, Type D-3, Polyphase, Induction Watthour Meters, above 150 Amperes, up to 650 Volts, 25 Cycles and above; 4-wire, 2-phase Circuits with Current Transformers. Front View.

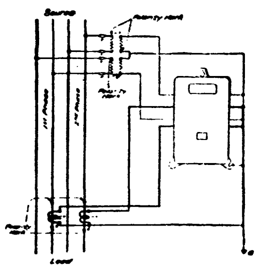
The Type D-6 polyphase watthour meter (Fig. 532) designed for house service on two- and three-phase circuits with either balanced or unbalanced loads. It is built self-contained, in ratings 5, 10, 15, 25, 50, 75, 100, 150 amperes, 110, 220, 440, 550 volts, 25, 40, 50, 60, 125, 133 cycles, for all circuits except 4-wire, 3-phase. Meters for 4-wire, 3-phase circuits are built self-contained in ratings 5, 10, 15 25, 50, 75 amperes only. This type was produced in 1915.

This meter is substantially a combination of two type I-14 meters in one case with a single shaft for the two so that the total registration is obtained on one dial. The general construction is similar to the Type I-14.

The full- and light-load adjustments are both operated by micrometer screws as in the I-14 meter. The inductive-load adjustments are operated from the front of the meter. The adjustment for each element is held by two screws directly under each disk.

This meter is provided with a mechanical adjustment for equalizing the torque of the two elements, which is operated from the front. The four brass caps between the disks protect this device from inadvertent change of adjustment.

The meter is finished in dull black and the terminal compartments are sealed separately from the meter proper. The weight is approximately 19 pounds.



NOTE:—"G" shows ground connection.

FIG. 525.—External Connections of Thomson, Type D-3, Polyphase, Induction Watthour Meters, above 650 Volts, 25 Cycles and above; 4-wire, 2-phase Circuits with Current and Potential Transformers. Front View.

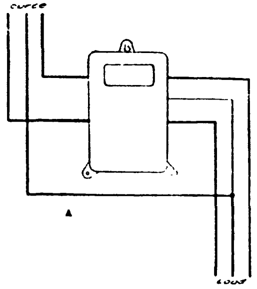


FIG. 526.—External Connections of Thomson, Type D-3, Polyphase, Induction Watthour Meters, 3-150 Amperes, up to 650 Volts, 25 Cycles and above; 3-wire, 2- and 3-phase and Monocyclic Circuits without Instrument Transformers. Front View.

On 3-wire, 2-phase circuits, wire "A" should be the common return; on monocyclic circuits, wire "A" must be the teaser wire.

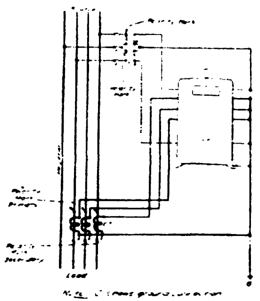


FIG. 531.—External Connections of Thomson, Type D-3, Polyphase, Induction Watthour Meters, above 650 Volts, 25 Cycles and above; 4-wire, 3-phase Circuits with Current and Potential Transformers. Front View.

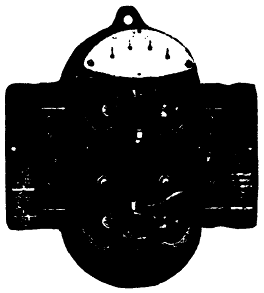


FIG. 532.—Internal View of Thomson Polyphase Watthour Meter, Type D-6.

CONNECTION DIAGRAMS FOR GENERAL ELECTRIC TYPE D-6 AND D-7 POLYPHASE WATTHOUR METERS.

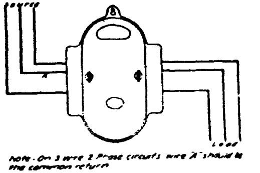

Source
A
Load
Note: On 3 wire 2 Phase circuits wire "A" should be the common return

FIG. 533.—External Connections of Thomson, Type D-6 and D-7, Polyphase, Watthour Meters, 5-75 Amperes, 110-550 Volts, 25-133 Cycles; 3-wire, 2- and 3-phase Circuits without Instrument Transformers. Front View.

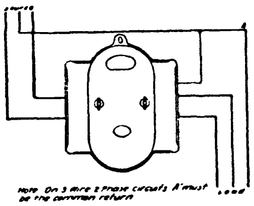
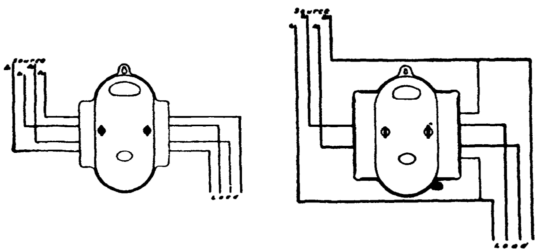

Source
A
Load
Note: On 3 wire 2 Phase circuits "A" must be the common return

FIG. 534.—External Connections of Thomson, Type D-6 and D-7, Polyphase, Watthour Meters, 100-150 Amperes, 110-550 Volts, 25-133 Cycles; 3-wire, 2- and 3-phase Circuits without Instrument Transformers. Front View.



5-75 Amperes

100-150 Amperes

FIG. 537.—External Connections of Thomson, Type D-6 and D-7, Polyphase, Watthour Meters, 110-550 Volts, 25-133 Cycles; 4-wire, 2-phase Circuits without Instrument Transformers. Front View.

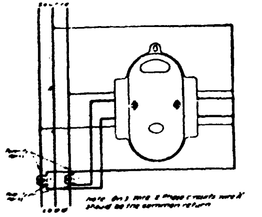

Source
Polarity Marks
Polarity Marks
Load
Note: On 3 wire 2 Phase circuits wire A should be the common return

FIG. 535.—External Connections of Thomson, Type D-6 and D-7, Polyphase, Watthour Meters, above 150 Amperes, 110-550 Volts, 25-133 Cycles; 3-wire, 2- and 3-phase Circuits with Current Transformers. Front View.

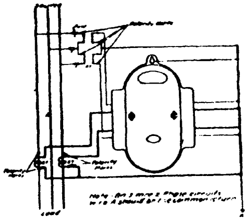

Source
Polarity Marks
Polarity Marks
Polarity Marks
Load
A
Note: On 3 wire 2 Phase circuits wire A should be the common return

FIG. 536.—External Connections of Thomson, Type D-6 and D-7, Polyphase, Watthour Meters, 25-133 Cycles; 3-wire, 2- and 3-phase Circuits with Current and Potential Transformers. Front View.

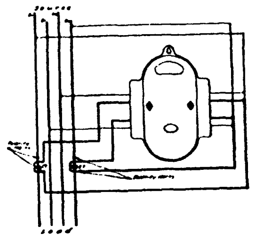


FIG. 538.—External Connections of Thomson, Type D-6 and D-7, Polyphase, Watthour Meters, above 150 Amperes, 110-550 Volts, 25-133 Cycles; 4-wire, 2-phase Circuits with Current Transformers. Front View.

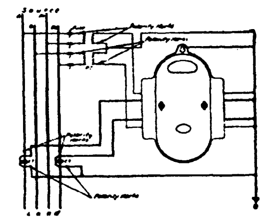


FIG. 539.—External Connections of Thomson, Type D-6 and D7, Polyphase, Watthour Meters, 25-133 Cycles; 4-wire, 2-phase Circuits with Current and Potential Transformers. Front View.

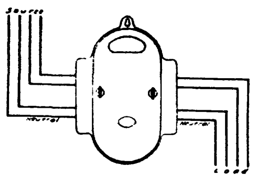


FIG. 540.—External Connections of Thomson, Type D-6 and D-7, Polyphase, Watthour Meters, 5-75 Amperes, Volts, 127 Y—220 Δ, 254 Y or 440 Δ; 25-133 Cycles; 4-wire, 3-phase Circuits without Instrument Transformers. Front View.

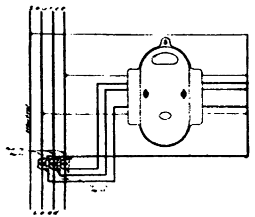


FIG. 541.—External Connections of Thomson, Type D-6 and D-7, Polyphase, Watthour Meters, above 75 Amperes, Volts, 127 Y—220 Δ, 25-133 Cycles; 4-wire, 3-phase Circuits with Current Transformers. Front View.

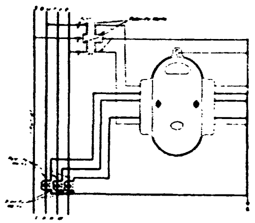


FIG. 542.—External Connections of Thomson, Type D-6 and D-7, Polyphase, Watthour Meters, 25-133 Cycles; 4-wire, 3-phase Circuits with Current and Potential Transformers. Front View.

Types DS-2, DS-3, DS-4 and DS-5 Meters.—The Types DS-2 and DS-3 Thomson watthour meters were designed for switchboard service for use upon two-phase, three-phase, or monocyclic circuits of balanced or unbalanced loads. They are built self-contained in ratings of 3, 5, 10, 15, 25, 50, 75, 100 and 150 amperes, 100 to 650 volts, 25 cycles and above, for use upon four-wire two-phase, three-wire two- and three-phase, and monocyclic circuits, and in ratings of 3, 5, 10, 15, 25, 50 and 75 amperes, 100 to 650 volts, 25 cycles and above for use upon four-wire three-phase circuits.

The former type of watthour meter has a cast metal cover with pebbled surface and with glass windows for observing the operation of the moving element and for reading the dials (Fig. 543). The latter type of watthour meter is similar in construction except that a rectangular glass cover is provided.

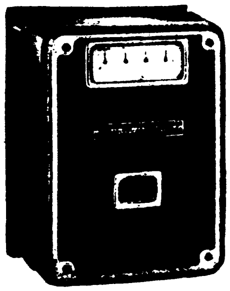


FIG. 543.—Thomson, Type DS-2, Polyphase, Induction Watthour Meter.

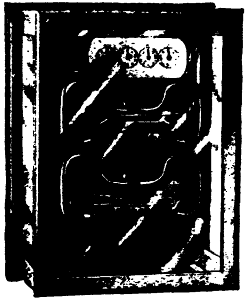


FIG. 544.—External View of Thomson, Type DS-5, Polyphase, Induction Watthour Meter.

The current and potential circuits of these meters are independent of each other, hence, these meters are interchangeable for use with, or without transformers.

The Types DS-2 and DS-3 meters are finished in dull black, the the raised portion of the Type DS-2 meter being finished in polished copper. Type DS-2 was produced in July, 1906, and Type DS-3 in May, 1906.

The Types DS-4 and DS-5 Thomson watthour meters superseded respectively the Types DS-2 and DS-3. The same general characteristics are maintained in these meters as in the Types DS-2 and DS-3, the slight difference being in the location of the electrical elements.The Types DS-4 and DS-5 meters were produced in September and December, 1908, respectively.

Type DS-6 and DS-7 Polyphase Watthour Meter.—The Type DS-6 polyphase watthour meter supersedes the type DS-4 and DS-5 for switchboard service. It employs the same electrical element as the D-6. All parts are attached to a cast frame, which in turn is mounted to a flat base. In addition to the important features incorporated in the design of the D-6 outlined above, such as micrometer adjustment for balancing the elements, reduction in size and weight, etc., the DS-6 is equipped with a set of test terminals which permit of either the introduction of a test meter or instrument in series with the current coils without opening the circuit, or of shunting the meter entirely by means of a jumper in order to test on another load, additional terminals being provided for connecting the current coil into the other circuit. While the meter is back connected, the test terminals are all on the front of the base, so that the desired connections may be effected without having to go back of the board. This meter is supplied with a cast iron cover or case, with two openings in the front. (Fig. 545.)

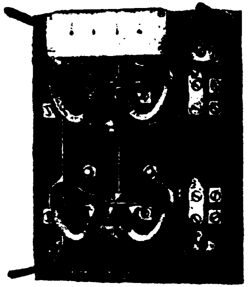


FIG. 545.—Internal View of Thomson, Type DS-6, Polyphase Induction Watthour Meter.

Detailed data and electrical features of the Type DS-6 meter are similar to those given for the type D-6 house-type meter.

The Type DS-7 meter is identical with the DS-6 except for the cover which is of glass. This type was produced in 1916.

Data from 1923 edition of Handbook for Electrical Metermen

SANGAMO WATTHOUR METERS

Sangamo meters are manufactured by the Sangamo Electric Company, Springfield, Illinois. They may be classified under two general divisions, as mercury motor type meters and as induction type meters. The mercury motor meters are made in both the ampere-hour and watthour types, and formerly in both direct-current and alternating-current models, the latter having been superseded by the induction type meter which is manufactured for both single-phase and polyphase service.

DESCRIPTION OF VARIOUS TYPES OF MERCURY MOTOR WATTHOUR METERS.—The fundamental principle and general construction of all Sangamo mercury motor meters is the same. They operate on the Faraday disk principle, according to which a metallic disk will rotate when current is passed between its axis and periphery if the current path is subjected to a magnetic field.

Type C, Direct-current Watthour Meters.—The first Sangamo mercury meter, known as the Type C, was produced in the fall of 1904. This meter was designed on the same fundamental principle as the present types, but owing to various defects which developed, its manufacture was soon discontinued, and it was superseded, in the fall of 1905, by the first Type D direct-current meter.

Early Type D, Direct-current Watthour Meters.—In the first Type D meter, a thin copper disk was completely immersed in mercury in a chamber formed of moulded insulating material, arranged with suitable copper contacts imbedded in the insulation at each extremity of a diameter of the chamber, and designed to carry current into and out from the mercury. The armature was provided with a hollow copper shell, or float, so that the buoyancy of the armature immersed in mercury was sufficient to give the entire moving system, consisting of the armature inside the chamber and the aluminum damping disk outside, a slight and positive upward thrust.

The rotating element, of the same general design as that used in the Type C meters, was considerably lighter in weight and the shaft had a removable lower pivot. The various elements, such as the measuring system, the damping system, and registering system, were mounted on a cast aluminum-alloy frame, secured to supporting posts by a three-point support to the base.

Arrangement of Field Elements.—In the upper piece of moulded insulation forming the mercury chamber, a steel plate, or ring, was imbedded so that it acted as a return for the lines of force emanating from a potential circuit magnet placed below the chamber and with its pole pieces having their centers on the same diametrical line as the contacts of the mercury chamber. With this arrangement, current passing between the contacts was subjected to the influence of the two fields passing through the disk in opposite directions, and thus a cumulative and continuous torque effect was obtained, depending upon the volume of current passing and the intensity of the field. With a field proportional to the voltage, and a current through the chamber equal or proportional to the load current, a torque was obtained practically proportional to the power delivered to the customer.

Drag Magnets and Damping Disk.—The necessary braking effect was obtained in the usual manner, by the damping disk acted upon by two permanent magnets held in the back of the meter rigidly with respect to the disk.

Register.—Motion was transmitted from the shaft to a recording train through a worm and worm wheel in the usual manner. The dials of the original Type D meter read in watthours. The register had five dials, with the first dial indicating 1,000 watthours per revolution of the dial pointer.

Mercury Chamber.—In the original Type D meter, as in all subsequent ones, spilling of the mercury during shipment or in handling was practically prevented by a construction of the mercury chamber somewhat like an invertible inkwell. A pocket, or space, was provided for the mercury to run into when a meter was turned upside down, so that there was very little opportunity for mercury to get out between the shaft and the ring jewel in the cover of the mercury chamber.

Later Type D, Direct-current Watthour Meters.—During 1906 and 1907, the Type D, direct-current meter was improved in various details until the spring of 1908 the meter was brought out in a form which was continued until 1913 with only minor changes. At the same time the Type F, alternating-current, mercury motor meter was put on the market. These models, the Type D meter and the Type F, are exactly alike in all structural details; in fact, in everything except the arrangements peculiar and necessary to the direct-current and alternating-current forms.

Conditions Causing Inaccuracies in Type D Direct-current Watthour Meters.—The Type D watthour meter has occasionally run fast on light load, or has crept, due to grounding out of some of the resistance in the circuit of the thermocouple, in types where the thermocouple is used. Running slow on heavy load has in some cases been due to the partial grounding out of turns in the potential coils, thus reducing the potential circuit field strength; and in the case of shunted meters, from an increase in the resistance of the bypass circuit through the meter, as compared with the shunt. On light load the principal troubles have been either in the middle ring jewel bearing, or in the lower bearing. There has been very little actual jewel trouble in the sense of jewel wear, owing to the flotation of the moving system in these meters, but some trouble was experienced through the collection of dross around the ring jewel in the cover of the mercury chamber between the jewel and spindle, which resulted in friction at light load. This trouble has been largely eliminated in present meters by the use of a steel tube which extends around the spindle into the mercury. Some trouble has been experienced with the lower, or guide ring, bearing in the bottom of the mercury chamber due to rusting, or gumming, and in the meter as now made, this has been largely overcome by the substitution of a ring jewel, like that used in the cover of the mercury chamber.

Some trouble was also found in the earlier meters through change in alignment of the motor element with respect to the upper bearing; this has been rectified in later meters by rigidly doweling and fastening all such parts.

In some cases direct-current meters have run slow on light load due to a breaking of the thermocouple compensating circuit, that is, the element of the thermocouple supplying current at low potential to the armature, and in such cases it is necessary to remove the thermocouple and substitute a new one.

Present Form Type D-5, Direct-current, Two-wire Watthour Meters.—The Type D-5 mercury motor watthour meter for direct-current superseded the types C, D, D3 and D4.

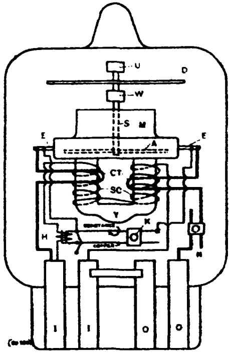


FIG. 546.—Diagram of Internal Circuits of Type D-5, 2-wire Meter. A, Armature; D, Damping Disk; E-E, Contact Ears of Mercury Chamber; H, Heater Winding of Thermo Couple; I-I, Binding Posts "from line"; K, Clamp Slider for Light-load Adjustment; M, Motor Element; N, Adjustment for Drop of Shunt; O-O, Binding Posts "to load"; S, Spindle; U, Upper Bearing; W, Worm Driving Recording Train; Y, Laminated Shunt Magnet; SC, Shunt Coils; CT, Compounding Turns to Build up Speed on Heavy Loads.

Construction Features of Two-wire Meters.—Fig. 546 gives the diagram of the internal circuits of the two-wire meter, together with explanatory nomenclature of elements. In Fig. 547 is shown the mercury motor of the two-wire meter in cross-section. Fig. 548 shows the two-wire meter with cover, and with the cover and recording train removed.

In the type D-5 meter the complete motor element includes the mercury motor, the shunt coils and magnet, the damping disk, and register. The mercury motor element is built up as a unit which is fastened into the base by three screws, and may be removed by disconnecting the series and potential leads and removing these three grid screws.

Shaft.—The damping disk and the motor disk (see Fig. 547), are carried on a common shaft which extends from the lower ring bearing up through the mercury chamber to the top bearing, thus eliminating the joint in the shaft as previously made, and assuring a straight shaft without a middle bearing. The mercury is kept from spilling by a long tubular sleeve which surrounds the shaft with a clearance of only 0.006 inch in the early form, and in later model by an arrangement of deflector tubes projecting from the lower surface of the hopper cap and a baffle plate mounted on a shaft as shown. This prevents spilling of mercury, even when subjected to the most severe handling, and at the same time allows a maximum clearance between rotating spindle and deflector tube.

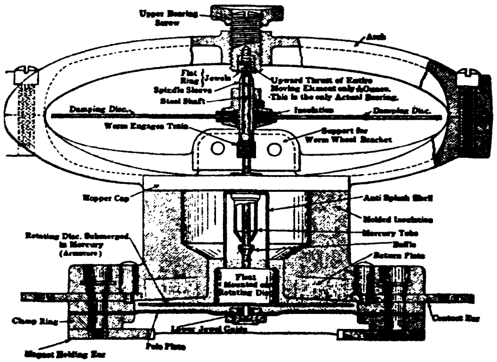


FIG. 547.—Cross Section of Mercury Motor of Sangamo 2-Wire, Direct-current, Type D-5, Watthour Meter, with Recording Mechanism, Field Magnets and Damning Magnets Removed.

The alignment of the moving system is established and maintained by two ring bearings at each end of the shaft, both being permanently centered in the same structure.

The recording train, which is also attached to the motor element, can be removed without the use of tools, and replaced without disturbing its alignment and the relative position of the worm and worm-wheel driving gears.

Armature.—Fig. 549 is an exploded view of the motor element, but without the recording train. It will be noted that the armature is slotted radially. The object of this is to guide the current in such direction with respect to the magnetic field furnished by the shunt magnet below, as to increase the effectiveness of the motor torque. This has resulted in an increase in the torque of from 40 to 60 millimetergrams.

Potential Element.—The potential coils as shown in Fig. 549 compose the entire potential element for circuits up to 130 volts. For use on circuits above this voltage and not exceeding 250 volts an internal resistance is furnished which connects in series with the potential coils. For circuits of voltages above 250 an external resistance box is furnished, which connects in series with the potential coils (Fig. 550).

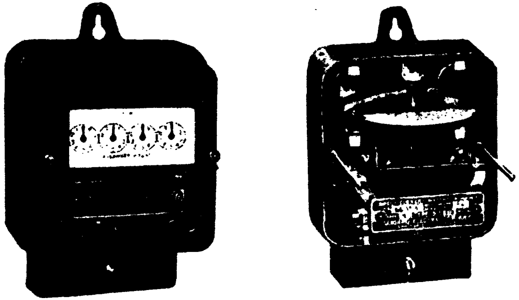


FIG. 548.—Sangamo Two-Wire, Direct-current, Type D-5, Watthour Meter, with Case on and with Case and Recording Train Removed.

Full-load Adjustment.—The permanent damping magnets are fastened solidly in the base, and are not moved for adjustment. The full-load adjustment is the same as in other types of Sangamo meters, and consists of a soft iron disk on a threaded shaft. This disk is situated above the gap of the permanent magnets as may be seen in Fig. 548 and by its position with respect to this gap determines the full-load speed of the meter. Raising the disk carries it away from the magnets thereby shunting less magnetic flux from the damping disk, and the meter consequently runs slower. Lowering the disk causes the meter to run faster.

Meters of the latest type are equipped with an auxiliary magnetic shunt which is attached to the base of the instrument and bridges the lower ends of the poles of the permanent magnet. This shunt is never used for adjustment except in cases where the range of the upper shunt is not sufficient to bring about the correct adjustment of speed, in which case the upper shunt is moved approximately to its mid-position and approximate adjustment made with the lower shunt. This is then set in position and final adjustment made with the magnetic disk at the top in the usual manner.

Frame, etc.—The motor element is supported on the base of the meter by a heavy grid which extends up and forms the clamping ring of the motor element. Thus the entire motor element is supported from the bottom on a large base.

The base is of cast iron, with bottom terminal box. The binding posts are encased in fibre, and the terminal box filled with a moulded insulation. The lower hanging screws are sealed in the terminal box.

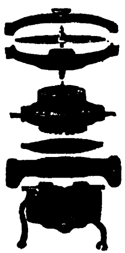


FIG. 549.—Field Magnet, Mercury Chamber, Frame and Moving Parts of Sangamo 2-wire, Direct-current, Type D-5, Watthour Meter.

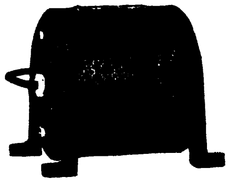


FIG. 550.—External Voltage Resistance for Sangamo, Type D-5, Watthour Meter, 400 Volts and above.

Friction Compensation.—The light-load compensation is obtained by means of a small thermocouple, the heating winding of which forms part of the potential circuit. This thermocouple is reversible, so that the meter may be connected in either the positive or negative side of the line.

In Fig. 551 is shown the complete light-load adjustment and thermocouple. A, is the thermocouple winding, consisting of two strips of dissimilar metal terminating in slotted ends held by screws B and C on a friction bracket. The thermocouple as shown is connected for the meter to be used in the positive side of the line. If the meter is to be used in the negative, loosen screws B and C, and shift slotted ends of thermocouple to position under screws C and D, and then tighten the screws firmly. This will reverse the effect of the thermocouple. Light-load adjustment is obtained by moving the clamp with hexagonal head screw E along copper wire F and resistance wire G. After moving clamp E and obtaining desired adjustment, the clamp must be tightened firmly.

Name Plate.—The name plate is held by screws passing through two insulating washers H-H, and these washers must be replaced on both sides of the plate if it is to be removed for any purpose, so that the supporting brackets of the light-load adjustment will not be short-circuited.

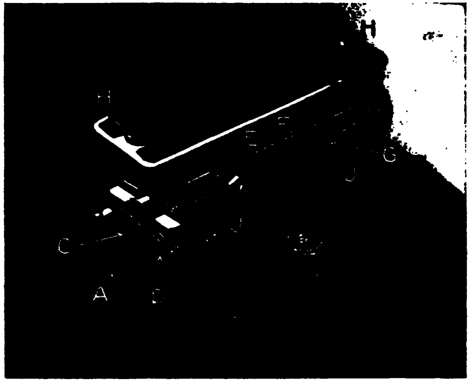


Fig. 551.—Thermocouple and Light-load Adjustment of Sangamo 2-wire, Direct-current, Type D-5, Watthour Meter.

Shunted Types.—All meters above ten amperes rating operate from shunts. For ratings from 25 amperes to 75 amperes these shunts are internal, being connected across the binding posts inside of the base. Meters rated from 100 amperes up are externally shunted. Externally shunted service type meters are furnished regularly with cable connector terminals (see Fig. 567). Shunts are furnished in any of three types, pocket, box or open type. Open type shunts may be had for any externally shunted meter (Fig. 552). Pocket type shunts are furnished only for 100 to 200 amperes ratings, and box type only from 100 amperes to 400 amperes.

Operating on the shunted principle, the relative resistance of shunts and meters are of primary importance. A sliding block adjustment is furnished in the series circuit of shunted meters by which they are adjusted at the factory, with their cable, to the exact drop of the shunt from which they will operate. This adjustment is shown at N, on the right hand side of Fig. 546. This adjustment is primarily a factory adjustment and should never be changed unless meter is taken down for repairs or used on a different shunt from that for which it was originally calibrated.

It is obvious that with the shunted construction, all Type D-5 meters may be disconnected from their shunts and tested as ten ampere meters.

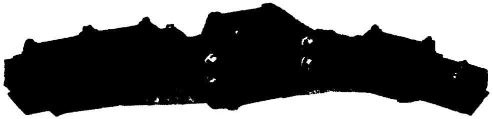


Fig. 552.—Open Type Shunts—400 to 3,000 Amperes—for use with Sangamo Meters.

Type D-5, Three-wire Meters, Vertical Construction.—Fig. 553 gives the diagram of internal circuits for the Type D-5, three-wire mercury motor type watthour meter for direct current, together with explanatory notes. Fig. 554 shows the mercury motor of this meter in cross-section. Fig. 555 shows meter with cover on, and with cover removed.

This meter represents the first three-wire mercury motor type, direct-current meter built. As may be noted from Fig. 554 the two mercury motors, one vertically above the other, are mechanically coupled together, the sum of their torque drives the generator or damping disk, and the revolutions are recorded in the usual way. The torque of the three-wire meter is somewhat greater than twice that of the two-wire, but the effective weight on the upper bearing is approximately the same.

Construction Features.—In its general construction the three-wire meter is similar to that of the two-wire, and only points of difference are described here.

The moving element of a motor-generator element, an insulating coupling, and a motor element, are connected mechanically in series. The damping disk is mounted at the top of the driving shaft and is insulated therefrom, as in the two-wire meter.

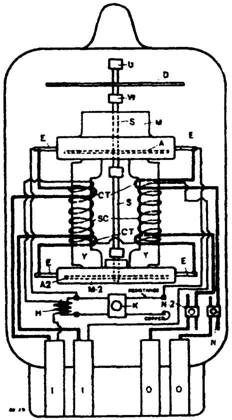


FIG. 553.—Diagram of Internal Circuits of Sangamo 3-wire, Type D-5, Direct-current, Watthour Meter. A, Armature of Upper Element; A2, Armature of Lower element; D, Damping Disk.; E-E, Contact Ears of Mercury Chamber; H, Heater Winding of Thermo Couple; I-I, Binding Posts "from line"; K, Clamp Slider of Light-load Adjustment; M, Upper Motor Element; M2, Lower Motor Element; N-N2, Drop Adjustments for Shunts; O-O, Binding Posts "to load"; S, Spindle; U, Upper Bearing; W, Worm Driving Recording Train; Y, Laminated Shunt Magnet; SC, Shunt Coils; CT, Compounding Turns for Building up Speed on Heavy Loads.

The lower end of the upper section of the shaft passes through the bottom of the mercury chamber, through a sleeve that projects up into the mercury chamber and inside the float. This sleeve carries a ring jewel that serves as a guide for the shaft and reduces the clearance between the shaft and the sleeve to such a small amount that the cohesion of the mercury is sufficient to prevent its passage through that clearance under the maximum pressure that can be exerted on it in operation.

The lower end of the upper section of the shaft fits into a coupling which extends to the upper end of the lower section and is thoroughly insulated at each end. The lower motor element shaft is fastened to an insulated coupling at its upper end. At its lower extremity it carries the armature disk of the lower mercury motor. The entire system is buoyed by a large float on the upper motor armature, assisted by the buoyancy of the lower disk which is somewhat greater than its own weight plus that of the insulating coupling.

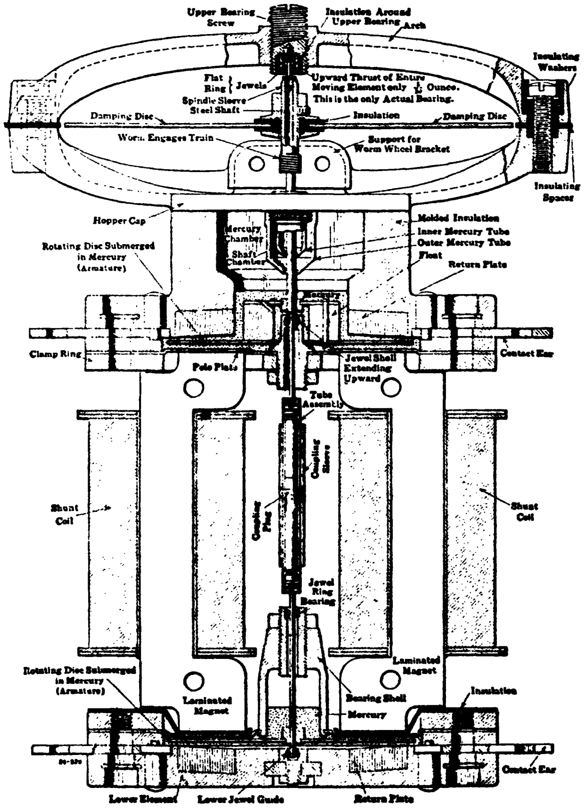


FIG. 554.—Cross Section of Mercury Motor of Sangamo 3-wire, Direct-current, Type D-5 Watthour Meter.

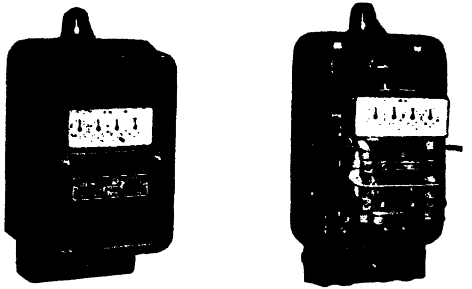


FIG. 555.—External and Internal Views of Sangamo, 3-wire, Type D-5, Direct-current Watthour Meter.

The moving system is somewhat heavier in air than the two-wire, but the pressure on the upper jewel bearing, or the effective weight, is no greater.

Both motor elements in their details of construction differ somewhat from those used in the two-wire meter. The motor field windings and structure, that is, the potential magnets, are assembled between the motor elements as shown in Fig. 555, and the whole clamped together and insulated. The potential coils are connected in series across the outside legs of the three-wire system, and the same magnetism passes through both elements of the meter.

Adjustments.—Compensation on light load is accomplished by means of a thermocouple connected across the lower motor element in exactly the same way as in the two-wire meter, except that the reversible feature is not furnished, this being unnecessary. The range of the single thermocouple is quite sufficient for the double element moving system.

A small adjustable shunt of high resistance is placed around the upper element. This enables an exact balance of the two elements to be obtained, as the upper element has initially a somewhat higher torque than the lower element, allowing a small balance of current to be shunted for the adjustment.

The entire motor element of the meter is carried on a single heavy grid, and after disconnecting the leads, it may be removed as a unit by simply taking out the four grid screws. As in the two-wire meter, the two permanent damping magnets are carried in the base, permanently clamped in position. The full load adjustment is obtained as in the two-wire meter.

Shunted Type.—For externally shunted meters, two shunts are required, one for each side of the line. The same general remarks apply to these various features, as were made concerning the two-wire meter.

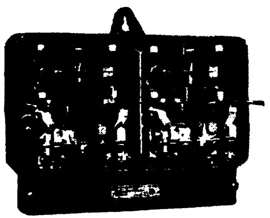


FIG. 556.—Sangamo Type D-5, 3-wire Watthour Meter, Cover Removed.

FIG. 557.—Sangamo Type D-5, 3-wire Watthour Meter, Cover in Place.

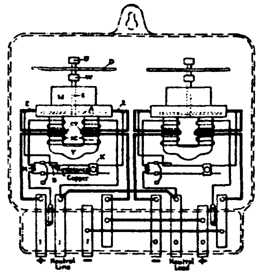


FIG. 558.—Internal Connections, Sangamo Type D-5, 3-wire Watthour Meter.

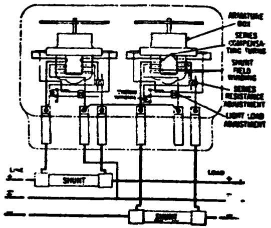


FIG. 559.—Connections of Sangamo Type D-5, Shunted, 3-wire Watthour Meter.

Type D-5, Three-wire Meter, Horizontal Construction.—For a number of years the Type D-5, 3-wire meter was made in the vertical tandem construction. This construction was superseded in 1918 by a new type intended for both service and switchboard installations. Figs. 556 and 557 show this construction in the service type. This meter is made self-contained in ranges from 10 to 75 amperes, inclusive, six terminals being provided so arranged that the positive, neutral and negative go under the binding posts 1, 2 and 3, counting from the left, while on the load side they go out in the order negative, neutral and positive through binding posts numbers 4, 5, and 6 respectively.

On the switchboard type separate disconnects are provided which facilitate testing and allow the meter to be completely disconnected for inspection and repair. Figs. 558 and 559 show the internal and external connections for both shunted and self-contained types.

External Connection Diagrams.

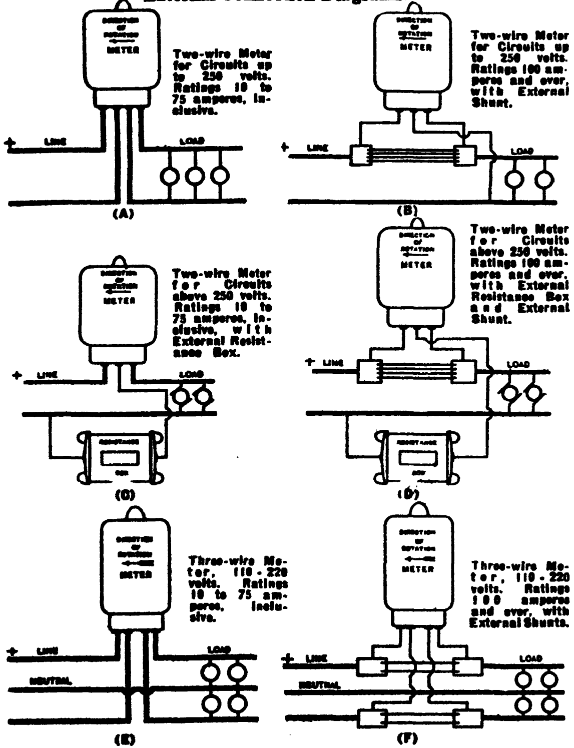

METER
Two-wire Meter for Circuits up to 250 volts. Ratings 10 to 75 amperes, inclusive.
+ LINE
LOAD
(A)
METER
Two-wire Meter for Circuits up to 250 volts. Ratings 100 amperes and over, with External Shunt.
+ LINE
LOAD
(B)
METER
Two-wire Meter for Circuits above 250 volts. Ratings 10 to 75 amperes, inclusive, with External Resistance Box.
+ LINE
LOAD
(C)
METER
Two-wire Meter for Circuits above 250 volts. Ratings 100 amperes and over, with External Resistance Box and External Shunt.
+ LINE
LOAD
(D)
METER
Three-wire Meter, 110-220 volts. Ratings 10 to 75 amperes, inclusive.
+ LINE
NEUTRAL
LOAD
(E)
METER
Three-wire Meter, 110-220 volts. Ratings 100 amperes and over, with External Shunts.
+ LINE
NEUTRAL
LOAD
(F)

FIG. 560.—External Connections of Sangamo, Type D-5, Direct-current, Watthour Meters.

Railway Applications, Economy Meters.—Watthour Meters of the mercury motor type are used on many thousands of electric railway cars and locomotives for checking the comparative operating efficiency of the men and the equipment, and by the use of supplementary dials, for showing when a car has done a predetermined amount of work sufficient to require car or equipment inspection. The energy saving induced by meters on cars range from 10 to 20 percent. The equipment inspection alone justifies the cost of installation. The Economy Power Saving and Car Inspection Meter is shown in Fig. 561.

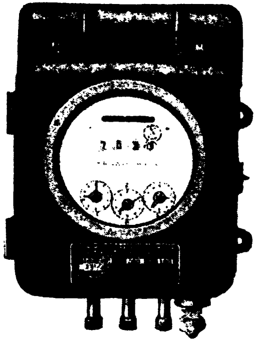


FIG. 561.—Sangamo Economy Railway Meter.

DESCRIPTIONS OF MERCURY MOTOR AMPERE-HOUR METERS.—The ampere-hour meter as now made was a reversion to the original type of mercury meter, although in the course of development, it was a modification of the Type D watthour meter.

In July, 1908, the first ampere-hour meter of this type was made for use as an indicator of the floating point of a large reserve battery. Ampere-hour meters were put on the market in the beginning of 1909.

Construction Features.—In the ampere-hour meter the same general features have been used throughout as in the Type D watthour meter except that a permanent driving magnet is substituted for the potential circuit energized magnet of the Type D meter. There is the usual arrangement of damping disk and magnets and the torque is proportional to current instead of power. By a recording mechanism, a record is thus obtained of ampere-hours instead of watthours, and the operation of an ampere-hour meter is exactly the same no matter what the voltage of the circuit may be.

Recording Mechanism.—On account of the many uses which have developed for ampere-hour meters, the Sangamo meter has been built with various modifications of base, recording trains, and auxiliary features. The usual form of recording train on ampere-hour meters is a large circular dial, having a dial hand adapted to show by its position on the dial, the condition at any time of the storage battery to which the meter is connected.

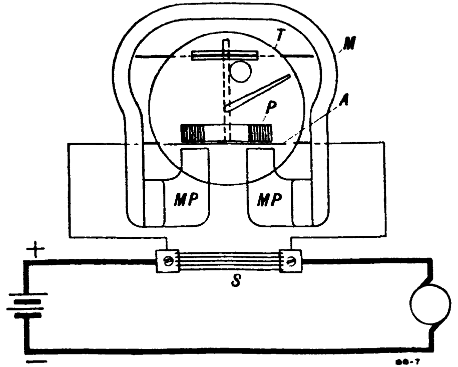


FIG. 562.—Circuit Diagram of Sangamo Simple Shunted Ampere-hour Meter.

By various combinations in the ampere-hour meter, and particularly a differential shunt adapted to make the meter run slower on charge than on discharge, a percentage of over-charge can be obtained automatically for a storage battery (Figs. 562 and 563).

The meters are used in connection with batteries on electric vehicles, on electrically-lighted steam railroad cars, in street car service, with central station batteries and for control of electroplating operations. By an arrangement of contacts operated by the dial hand when the battery is fully charged, the ampere-hour meter can be used as a relay to cut off the battery at full charge through an auxiliary shunt trip circuit breaker.

Another type of recording train used on ampere-hour meters is the duplex type, having one row of four dials for charge and a second row for discharge so that the entire input and output of a battery may be recorded on the single duplex register.

Application to Electroplating.—The ampere-hour meter is employed in electroplating to afford a more convenient and accurate method of obtaining the amount of metal deposited in a plating bath in a given elapsed time than may be obtained from noting the average current flow during the period by observing an indicating ammeter.

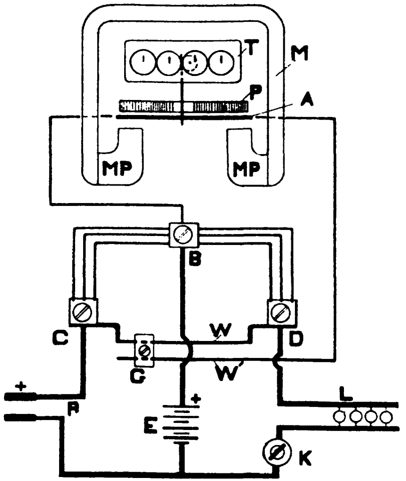


FIG. 563.—Sangamo Ampere-Hour Meter with Differential Shunt.

Electroplating Type Ampere-hour Meter.—A large movable pointer operated by a knob in the middle of the glass window over the dial face is provided, to be set at the point on the dial indicating the amount of metal which it is desired to deposit in any particular plating operation, thus giving a plain reference point for the workmen and facilitating the discontinuance of the plating when the ampere-hour meter dial hand reaches the predetermined figure on the scale through electrical contacts.

Electric Vehicle Application.—The ampere-hour meter has an application to electric vehicles, inasmuch as it affords a direct, convenient and accurate method of determining the "miles in the battery," without noting the readings of the dashboard ammeter and voltmeter in the pleasure vehicle, or truck. Practical economy in operating electric vehicles, or electric boats, and safety to the propelling battery alike make desirable a method of determining, within the intelligence or skill of the driver, the amount of electrical energy carried by the vehicle.

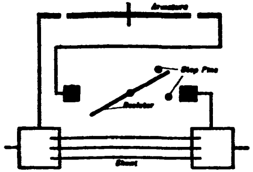


FIG. 564.—Circuit Diagram of Sangamo Variable-Resistor Type, Ampere-hour Meter. (Old Style.)

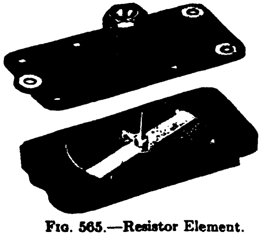


FIG. 565.—Resistor Element.

Automobile Type Ampere-hour Meter.—The auto-type ampere-hour meter affords a continuous record of the actual ampere-hours (virtually the miles) available in the vehicle battery during every trip, and it does this by integrating the current discharge of the battery and showing the progressive lowering of total charge in the battery by a dial hand which sweeps over a dial calibrated in ampere hours. In charging the battery in the garage the dial hand may be moved over the scale in one direction registering the energy stored in the battery until the full charge has been put in. On starting out on a trip, the dial hand, therefore, shows the driver the total ampere-hours available in his battery; and as the vehicle travels over its route the dial hand moves backward over the scale, showing a progressively diminishing number of ampere-hours left in the battery, until the arrival of the dial hand at the zero indicates the limit of discharge of the battery. Most electric vehicle manufacturers prefer to use the meter operating the dial hand in the reverse direction from that explained above, so that, as the battery is discharged, the dial hand moves up the scale, moving back to the zero on charge. This arrangement allows the use of a contact at the zero point which may be employed to trip a circuit-breaker when the battery is fully charged. More recently two-rate charging schemes have been employed which enable the battery to be charged in less time and without injury to the battery.

Variable-Resistor Type, Ampere-hour Meter.—In cases where the battery floats on the line, that is, where the load current may come either from the battery or the generator, the differential shunt meter cannot be used. This is evident, since if current were taken from the generator it would pass through both legs of the shunt in series (see Fig. 563). Therefore, in order to accomplish automatic regulation of overcharge in floating batteries, the variable resistor type of meter is built.

In this type there is introduced in the motor element circuit, either in parallel or series with the motor element, a resistor that has two distinct values of resistance, one for each direction of current. Fig. 564 shows the connection of such a meter with the resistor in series with the motor element.

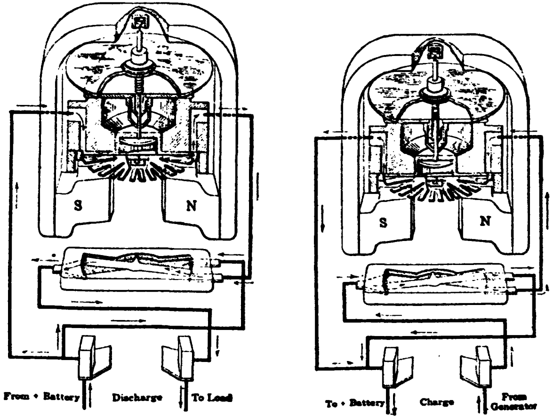


FIG. 566.—Diagram of Electrical Circuits, showing Charge and Discharge.

Construction Features.—The resistor itself is an application of the mercury motor principle. It consists of a copper bar pivoted and floated in mercury, its rotation being limited by two stops. The magnetic field is supplied by the same poles that produce the fields in the motor element. In one position the copper bar is in direct line between the contacts, while in the other position the bar is at an angle to the contacts, and the high-resistivity mercury path is longest, that is, the resistance is maximum.

In practice the vane is usually arranged to decrease the current through the motor element on charge and vice-versa on discharge, causing the meter to run slow on charge and automatically give the desired percentage of overcharge.

A later design has a moulded insulation box in which the copper vane is pivoted. This is shown in Fig. 565. Current is carried to it from the box by means of contacts moulded into the chamber. The mode of operation is similar to the earlier types with some modifications in the electrical circuits.

Fig. 566 shows the diagram of electric circuits as well as the position of the vane for both directions of current flow.

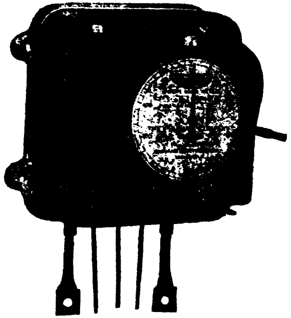


FIG. 567.—Ampere-hour Meter Equipped with Variable Resistor.

On account of the wide range of application of meters having the variable resistor feature, it is now generally recommended that this type be used in preference to Sangamo meters having the differential shunt in any service where it is desired to give overcharge to the batteries automatically. Fig. 567 shows a meter equipped with this feature.

Ampere-hour Meters Used for Measurement of Electrical Energy.—While ampere-hour meters are used universally in connection with apparatus calling for the measurement of quantity of electricity, their use in measuring electrical energy has not until recently been considered in the United States. Inherently such meters are still ampere-hour meters having registers arranged to record electrical energy under the assumption of constant voltage applied to the system. The Sangamo type NH meter is intended for this class of service.

Mercury Motor Meter, Type NH.—This meter is somewhat simpler than the Type D mercury motor meter. The moving system consists of a solid copper disk submerged in mercury contained in an armature chamber as in the Type D-5 meter. Two powerful permanent magnets located on opposite sides of the main spindle furnish the magnetic flux which serves to create both the driving and the retarding torque. The current is conducted through the armature from metallic ears located on opposite sides of the armature chamber. The electrical losses in this meter are extremely low since no potential circuit is used and the main current passes directly through the armature. Fig. 568 shows the meter complete with cover while Fig. 569 shows the meter without cover.

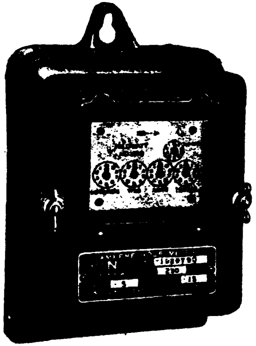


FIG. 568.—Type NH Ampere-hour Meter.

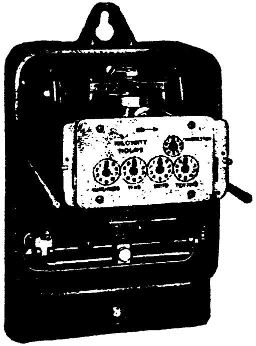


FIG. 569.—Type NH Ampere-hour Meter, Cover removed.

Construction Features.—Due to the fact that both damping and driving torque is generated within the copper disk located in the armature chamber, the moving system is extremely simple in construction. The main spindle carries the lower and upper pivots, a worm being provided to operate the register.

Full-load Adjustment.—The registration rate of the meter is varied through an adjustable slider which varies the resistance in series with the armature. A diagram of electrical circuits is shown in Fig. 570.

Railway Applications.—The ampere-hour meter is sometimes used on electric railway systems, to check and record the actual amount of current consumed by each car, and supplies a record of comparative current consumption, enabling electric railway managers to offer a strong incentive for the motorman to handle his car to the best advantage and with economy of current.

Distantly Operated Type.—A variation in the ampere-hour meter is the distant operated type in which the meter proper has a special recording train arranged to close a circuit at definite ampere-hour intervals and by this action an electrically operated mechanism is caused to move step by step. With this arrangement the register mechanism can be placed at any point desired remote from the meter (Fig. 571).

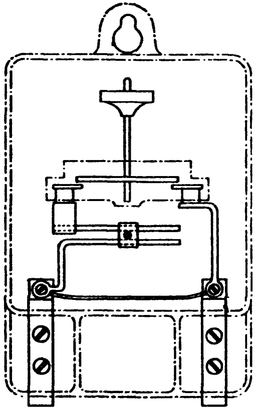


FIG. 570.—Diagram of Electrical Circuits Type NH Ampere-hour Meter.

The distant dial mechanism has been redesigned and can be applied to the differential shunted meter, so that automatic control of the overcharge is possible with this type as with the standard type of meter. This type of dial is also applicable to watthour meters.

Types of Registers.—On account of the many special purposes for which ampere-hour meters are used, and the various types of recording trains which it has been found necessary to build for these purposes, the data on these trains cannot be given exactly in the same way as for standard watthour meters. Given herewith is a table (No. 95) containing the data for ampere-hour meters compiled in the same form as that for watthour meters, so far as is possible to do so. The numerical value of one revolution of the first dial pointer, the register constant, the gear ratio, etc., cannot be given, however, in the same way as given for watthour meters.

Recording trains, or registers, as used on Sangamo ampere-hour meters, are of three general types:

1. *Standard 4-dial Register.*—These are used on Type D meters where it is desired to keep a record of total charge or discharge, but not both.

Meters with such dials are usually used in pairs on loads subject to rapid reversals, and each meter is equipped with detent on shaft to prevent backward movement of dials.

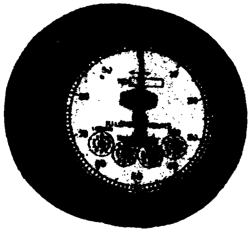


FIG. 571.—Distant Dial.

2. *Duplex Recording Trains.*—Register has two rows of four dials each, one for charge and one for discharge, the gearing for each row being arranged so that when one set of dials is recording the other is stopped.

3. *Register with Large Dial.*—A large dial, 3½ inches in diameter, reads in various unit values of ampere-hour per revolution. It has one hundred divisions, every tenth division being heavy, and numbered. The large dial may have within it, below the center of the large dial, a row of four totalizing dials, reading from left to right, instead of from right to left as in most registers. (This came about through certain difficulties in gearing up for the totalizing train.) The totalizing dials are arranged to record total discharge or charge, but not both, being geared to move when large hand is moving in one direction, but held by a detent when it reverses.

This type of register is also made to record in various units proportional to ampere-hours, such as weights of metals for electroplating, and squared-amperes-hours for measuring losses in conductors, and may be provided with resetting, alarm-giving or circuit-opening features.

Constants.—The test constant for a meter of a given rating, is the same, irrespective of the type of register used, but the register constants, register ratios and gear ratios vary according to the type of register as noted on the table following.

NOTE—With duplex trains, if both charge and discharge dials are arranged to read in ampere-hours, the values in the table apply to both, but if charge row is geared to read in kilowatt-hours at normal charging voltage, say 120, the first right-hand dial in the charge row reads 10 kilowatthours per revolution in all ratings up to and including 200 amperes.

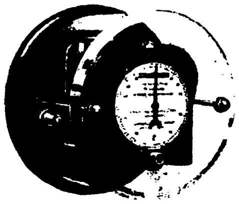


FIG. 572.—External View Sangamo Switchboard Type Ampere-hour Meter.

Sangamo ampere-hour meters are, for many classes of work, set to run slow on charge or fast on discharge, in a fixed ratio. Table 95 gives constants for the discharge performance of meters set to run correct on discharge. If set to run slow on charge, the constants for the performance on charge are modified according to the percentage by which the speeds on the two operations differ. Charge and discharge refer to the cycles of operation of the storage batteries on which such meters are commonly used.

Above values are for types (1) and (2) registers, as per notes herewith. In case of type (3) registers, with large circular dials, the large dial may have any desired standard value for one revolution of the pointer thus reading direct 100, 200, 300, 400, 500 or 600 ampere-hours to a revolution, and each tenth division being numbered accordingly. For larger values, a register constant of 10 is employed.

From the preceding it is evident that the register ratio and the gear ratio, for type (3) registers, will be variables, as the dial value has no definite relation to the meter rating.

When totalizing dials are present, they are always geared so that the first left-hand dial reads 100 ampere-hours per revolution, irrespective of the value of the large dial, unless the latter is greater than 600, in which case the reading of totalizing dials must be multiplied by 10.

Conditions Tending to Cause Inaccuracy in Ampere-hour Meters.—Ampere-hour meters are subject to the same general statements as given under Type D, and Type F except that in the ampere-hour meter there are no windings of any kind to change characteristics and thus change the speed of the meter.

On the other hand, in the ampere-hour meter the large permanent driving magnet is subject to a possible decrease in strength through age, or vibration in service, and if this happens a meter will have a tendency to run slow.

In the ampere-hour meter the tendency to run slow on light load is always more pronounced owing to the fact that there is no friction compensation.

SANGAMO INDUCTION TYPE WATTHOUR METERS.—The early Sangamo watthour meters for use on alternating-current circuits were designed on the usual induction motor principles explained in Chapter III, and consisted, therefore, of an induction motor element, operated by a rotating magnetic field interacting with induced currents in a closed circuited rotor; a generator element to provide load and braking effect for the motor element, and a revolution recording mechanism. These were combined, in general, in a manner to produce a commercial electricity meter of what is known as the induction motor type. The earlier types were known as the Gutmann meters.

Gutmann Induction Meters, Type A.—The original Gutmann induction watthour meter was developed in 1898 and put on the market in the spring of 1899. In this meter the rotor was an aluminum cylinder, slotted in spiral lines, and with damping disk riveted on the lower end of the cylinder. The cylinder was acted upon by a U-shaped potential circuit magnet and a pair of open series coils without iron cores, held on a supporting bracket by porcelain spools.

Adjustments.—Heavy-load adjustment in this meter was obtained by moving the permanent magnet in or out on the damping disk and light-load adjustment by moving a crescent shaped laminated iron core within the cylinder, this being a continuation of the potential circuit magnet outside the cylinder. The Type A Gutmann watthour meter was not provided with any compensation for inductive load, that is, the potential circuit magnet was not lagged. As this meter was only made for a short time, and was superseded by the Type B, or disk type, no attempt has been made to give a description in detail of its construction or to give data on it.

Gutmann Induction Meters, Type B.—The disk type of Gutmann meter was a development from the earlier cylinder type. In the Type B the rotor consisted of an aluminum disk with spiral slots arranged so as to give a torque effect between the potential circuit and series fields, which were placed with their effective centers in a radial line so that no torque was exerted on an ordinary blank, or unslotted disk. The potential circuit magnet consisted of two sets of laminations bolted together so as to form a single air gap, the magnet being energized by a coil on the rear arm of the upper, or main portion. The series coils were carried on an aluminum bracket between the gap of the potential circuit magnet and the center of the disk; one coil above, and one below the disk, each coil having within it a small bundle of laminated iron, not having, however, any complete or return magnetic circuit for the lines of force between the two coils.

Adjustments.—The damping magnet was placed on the opposite side of the center from the driving element and adjustment for speed was obtained by swinging the damping magnet in or out from the center of the disk toward the edge, in the usual manner.

Light-load adjustment was obtained by means of a soft iron vane attached to the inner side of the potential circuit magnet, and with a foot at the lower end adapted to act upon the disk in conjunction with the main potential circuit field. The iron strip was surrounded by a short-circuited conductor so as to have a considerable difference in phase in the flux from the foot of the vane and the main potential circuit field. By raising and lowering this vane, or by swinging it backward and forward, a light-load adjustment was obtained.

Compensation for inductive load was obtained by a heavy band of copper placed around the lower arm of the potential circuit magnet, the band being left open on the lower side and arranged with a copper, or iron, loop which could be moved in and out of blocks on the band to vary the resistance of the short-circuited secondary composed of the band and loop. By moving this loop an adjustment was obtained for low power factors.

General Features.—The recording train of this watthour meter was of the five dial type, reading in watthours, and was driven from the shaft of the meter through a worm and worm wheel.

The bearing was a cup sapphire jewel held in a setting above a light spring, and the lower pivot was polished directly on the disk shaft so that it was necessary to either repolish, or replace, a shaft in case of a pivot proving defective.

This type of watthour meter was made with both cast aluminum and glass cases, and was manufactured in considerable quantities until November, 1903. The manufacture of the Gutmann watthour meter was discontinued at that time in the United States, owing to patent litigation, but was continued about three years longer in Canada.

Sangamo Induction Meters, Type H (Original Model).—The Type H single-phase induction watthour meter was placed on the market in 1911, and manufactured in practically its original form until October, 1914, when it was superseded by the new model Type H, described later.

The Type H single-phase induction watthour meter consisted essentially of a light aluminum disk armature subjected to the action of potential circuit and series fields, the speed being controlled by permanent magnets in the usual manner, and the motion transmitted to a four dial register by a worm on the disk shaft.

Field Arrangement.—The field arrangement of this meter differed somewhat from former induction meters, but resembled in some respects the arrangement of the Gutmann induction meter built by this company some years ago. That is to say, the Type H embodied essentially a potential circuit magnet entirely independent of the series magnetic structure, but in the construction of the moving system, torque, etc., was very different from the Gutmann meter.

On account of the field arrangement, all parts except the potential circuit magnet were carried on a cast iron grid. This is shown in Fig. 573. The laminated crescent shaped plate forming the return path for the series magnetic field was held above the armature and did not have to be removed in repairing the meter.

Moving Element and Bearings.—The moving element consisted of an aluminum disk 3½ inches in diameter with a weight of 15.4 grams, although the first meters of this type had a disk weighing about 18.6 grams. The disk was carried on a brass shaft with removable double ended lower pivot and a worm was cut on the upper end of the shaft above the disk.

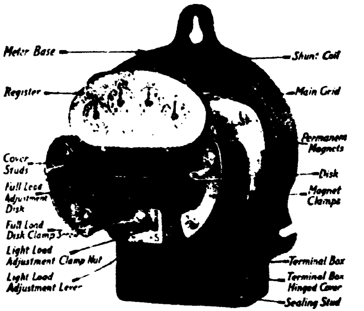

Meter Base
Register
Cover Studs
Full Load Adjustment Disk
Full Load Disk Clamp Screw
Light Load Adjustment Clamp Nut
Light Load Adjustment Lever
Shunt Coil
Main Grid
Permanent Magnets
Disk
Magnet Clamps
Terminal Box
Terminal Box Hinged Cover
Sealing Stud

FIG. 573.—Sangamo, Type H, Single-phase, Induction Watthour Meter (Original Model).

The lower bearing as first supplied with these meters consisted of the ring jewel and a flat jewel, but it was found that this type of bearing had a tendency to cause rattling, particularly in low frequency meters, so that this type of bearing was superseded by a cupped sapphire lower jewel bearing mounted fixed in the lower bearing post and with a sleeve above it which prevented the shaft dropping out of position during shipment, or when the meter was handled. The two types of lower bearing were made with bearing screws exactly interchangeable so that either might be substituted for the other.

Adjustments.—The meter had two adjustments as shown in Fig. 573. The full-load adjustment was obtained by means of a soft iron disk mounted on a vertical screw so that it could be moved relatively to the lower jaws of the two permanent magnets, thus varying the flux cutting the disk. A range of about 25% in speed was obtained by this adjustment.

The light-load adjustment consisted of a copper vane carried on a brass lever which projected down in front, on each side of the portion of the grid carrying the lower bearing and full load adjustment. The vane stood in the gap of the potential circuit magnet beneath the disk, and by moving the lever at the front of the meter, a slight distortion of the potential circuit was caused, thus giving an adjustment on light load either, backward or forward.

Creeping was prevented by two small holes punched in the aluminum disk. No adjustment was provided for inductive load compensation as a winding on the tip of the potential circuit magnet just below the potential coil was provided and adjusted at the factory to give approximately correct compensation at 50% power factor. When desirable to have very close compensation at low power factor, the terminals of this winding could be disconnected and a small amount of resistance inserted so as to bring the potential circuit field in exact quadrature with the impressed e.m.f.

Detailed Data.—The Type H watthour meter was so designed as to be shielded from severe short circuits or external magnetic fields, and the series coils were designed to have a continuous overload capacity of 100%.

The torque in the first Type H watthour meter, having a heavier moving system, was 50 millimeter-grams at 110 volts, 60 cycles. In the meter as furnished with the lighter moving element the torque is slightly over 40 millimeter-grams, giving a ratio of torque to weight of about 2.8.

The meter was supplied in all ratings from 5 to 100 amperes inclusive, 2-wire and 3-wire, without current transformers, and from 150 amperes upward with current transformers.

The meter had a four dial porcelain register face, reading direct in kilowatthours for all ratings and was furnished either with glass, or pressed aluminum, case; black finish.

The connection box was similar to that used on former Sangamo watthour meters, being at the bottom of the meter. The cover was arranged to swing down at one corner so that it may be sealed at the other corner when closed.

Test constants for this meter are marked in watt-seconds on top of the meter register.

The register ratio equals 200 times the number found marked on the back plate of the register.

The gear ratio equals 10,000 times this number.

This type of meter was produced in March, 1911.

Polyphase Type H Watthour Meter (Original Model).—The polyphase Type H meter was placed on the market in 1912, nearly two years after the single-phase meter as above described was brought out. The polyphase meter as originally built was continued without change until early in 1915, when it was superseded by the new model Type H, as described later.

Construction Features.—The polyphase meter had two elements carried on one main grid, each element in itself being exactly like the complete element of the Type H single-phase meter. The disks of the two elements were mounted on a single shaft transmitting motion through a worm at its upper end to a standard recording train, exactly as used in the single-phase meter. The arrangement of upper and lower bearings, lower pivot, full- and light-load adjustments, and inductive-load compensation, were exactly the same in the polyphase as in the single-phase meter. As in the single-phase meter, by removing the grid screws, the entire structure of the meter is accessible, only the shunt magnets being left on the base when the grid was removed.

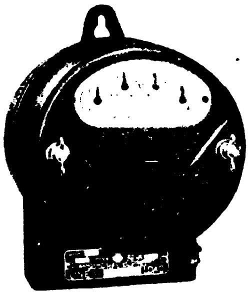


FIG. 574.—External View of Sangamo, New Model, Type H, Single-phase, Induction, Watthour Meter.

Adjustments.—An arrangement was also provided in this polyphase meter, by which the turning of a screw on the front of the grid just between the two sets of permanent magnets varied inversely the gaps in the series magnets of the two elements, so that an absolute balance in torque of both elements could be obtained without varying the resistance or turns in either the shunt or series elements of the meter. The construction was also such that one element had practically no effect on the other.

Detailed Data.—The polyphase meter of this type had a full-load torque of 85 millimeter grams, and the moving element weighed 32 grams, slightly more than double the weight of the single-phase element. The ratio of torque to weight was, therefore, approximately the same as in the single-phase, 2.6. The electrical performance of the meter, that is, on varying load, frequency, voltage, temperature, etc., was exactly that of the single-phase meter previously described.

Sangamo Type H Induction, Watthour Meter (New Model).—The new model Type H meter of the Sangamo Electric Company was brought out in October, 1914, in the single-phase type, and in January, 1915, in the polyphase type. As compared with the original model, this meter embodies many refinements in construction that have increased both the initial and the sustained accuracy, facilitated the work of adjustment and decreased the cost of labor and repairs.

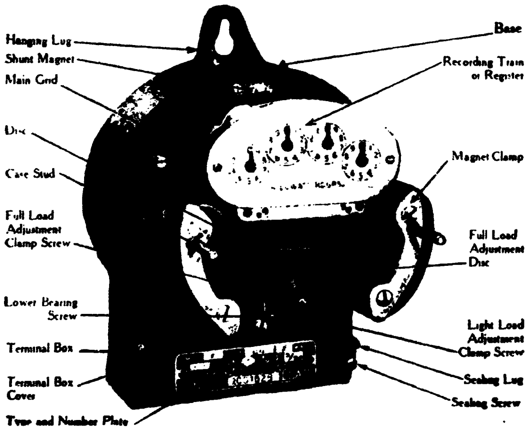


FIG. 575.—Annotated Internal View of Sangamo, New Model, Type H, Induction, Watthour Meter.

Construction Features.—The general dimensions of this model are the same as those of the original model already described except that the terminal box on meters of lower ratings has been changed. The lower hanging screws for the single-phase meter in all ratings are now sealed inside the terminal box. The insulating compound used in the terminal box is absolutely fireproof, and the binding post bushings are made of moulded insulation instead of soft rubber.

The name plate is carried on the door of the terminal box, and carries complete data relating to the meter, including the current, voltage and frequency rating, the disk constant, and the serial number.

Figs. 574 and 575 show the single-phase meter with and without cover.

The magnetic structure is changed in certain details, as shown in Fig. 576. The series magnet is fastened in the base with the shunt magnet, as is also the series return plate, so that it is not necessary to disconnect the series leads in order to remove the main grid and all that is carried thereon, and leave the magnetic structure exposed. The separate mechanical construction of the potential and series magnets is retained and as before, the potential magnet may be replaced as a unit. The laminations of the series magnet are riveted, and the form is such that the coils in ratings up to and inclusive of 100 amperes, may be slipped over the pole pieces.

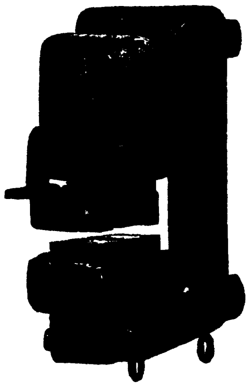


FIG. 576.—Magnetic Structure of Type H Meter.

A spring clip is used for fixing the series coils in position without danger of injury to the insulation.

The main grid carries all parts of the meter except the magnetic structure, i.e., the train, moving element, bearings, permanent damping magnets, and light- and full-load adjustments.

Adjustments.—The light-load adjustment is entirely different from that formerly used. The principle involved is exactly the same, the changes being in the mechanism for manipulating the device. The shape of the vane is somewhat changed. The vane is mounted on a shaft carried by a brass bracket fastened with screws to the back of the grid, as shown in Fig. 577. On the lower end of the shaft is riveted a sector with teeth milled in the edge. These teeth engage a screw, the head of which is accessible from the front of the grid. The adjustment has a micrometer action, and the head of the screw is provided with a scale to indicate the amount of rotation.

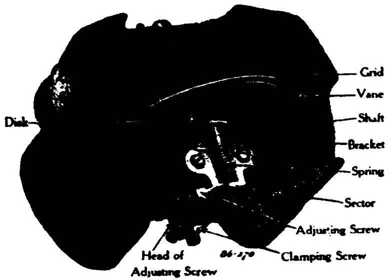


FIG. 577.—Grid Showing Adjustments of Type H Meter.

Bearings.—The moving element is nearly the same as in the old Type H. The lower pivot is made of high grade hardened steel with a highly polished spherical surface on one end, the other end being inserted into the shaft with a friction tight fit. A brass cylindrical cup permanently swaged on the lower end serves the manifold purpose of preventing the moving system from getting out of place during shipment, foreign matter from getting into the bearing, and injury to the polished surface from handling. Instead of circular anti-creeping holes in the disk, narrow slots are used, two in number, situated diametrically opposite each other, nearly parallel, and on chords of the circle of rotation. Fig. 578 shows the entire bearing system of the single-phase meter in cross-section.

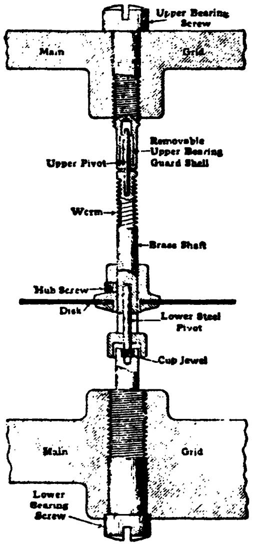


FIG. 578.—Bearings and Moving Element of Type H Meter.

Polyphase Type H Meters (New Model).—The new model Type H polyphase meter was brought out in January, 1915, following the single-phase type. This meter is shown with and without the cover in Figs. 580 and 582. Similarly to the old type, this meter embodies two single-phase elements, in general construction exactly like those of the single-phase meter. The moving element has two disks mounted on a single shaft.

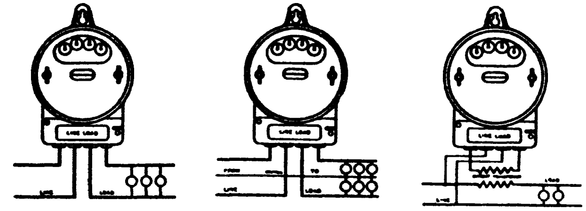
Adjustments.—In this model only one full-load adjustment is used, this being in conjunction with the permanent magnets of the lower element. The range given by the one adjustment is sufficient, and this change makes it possible to remove the entire moving element from the front by simply taking off the train and unscrewing the upper and lower bearings.

The micrometer light-load adjustment, as described for the single-phase meter, is incorporated in the polyphase meter, there being one adjustment for each element.

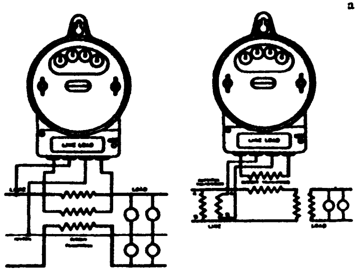
The balancing adjustment for the two elements is also retained. Due to the changes in the magnetic structure, certain mechanical changes have been necessary in order to make this possible.

Terminals.—As in the new model single-phase meter it is not necessary to disconnect any of the leads of the polyphase meter in order to remove the grid with all that is fastened to it. This involves simply the removal of the four grid screws. The side hanging screws of the polyphase meter are sealed inside the terminal boxes, as shown in Fig. 582.

External Connection Diagrams.



2-wire, for 5-100 Amperes. 3-wire, for 5-100 Amperes. 2-wire, for 150 Amperes and Above.



3-wire, with Current Transformers, for 150 Ampere and above. All Ratings with Current and Potential Transformers.

Fig. 579.—External Connections of Sangamo Type H (All Models) Single-phase Watthour Meters; 2- and 3-wire Meters, with and without Instrument Transformers, all Ratings.

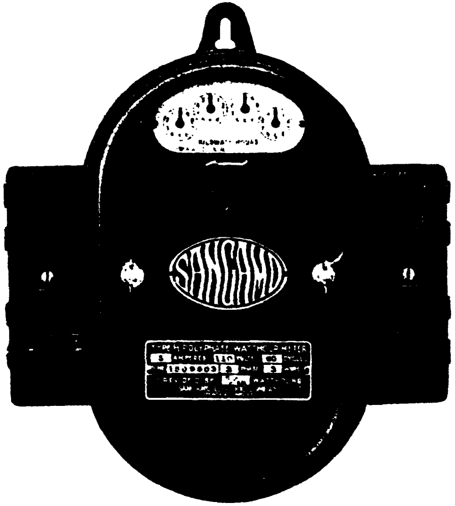


Fig. 580.—External View of Sangamo, Type H (New Model), Polyphase, Watthour Meter.

Test clips are provided between the incoming load and potential winding post for each phase so that without removing the cover from the meter, connections may be changed within the incoming terminal box, permitting a meter to be tested with independent potential or potential from the line.

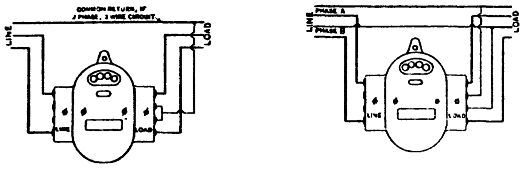
In a later modification of this meter the magnetic structure for each element is isolated by providing a barrier between the magnetic circuits of each element. Balance is obtained by the movement of the auxiliary path for the series flux. In this case, the grid is solid and does not have the opening provided in former models, for balancing the elements.

For measuring 4-wire, 3-phase energy a variation of this meter is obtainable which has three separate single-phase elements, mounted vertically, with three disks connected through one shaft to a recording train.

Conditions Causing Inaccuracy in Sangamo Induction Meters.—*Gutmann Meters Type B.*—The principal cause of running fast in these watthour meters was weakening of the permanent magnets.

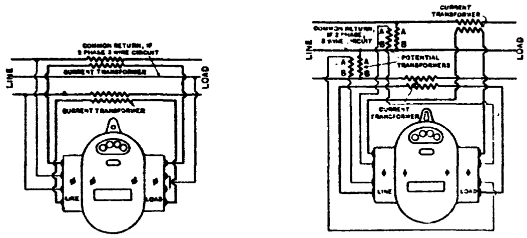
The principal cause of running slow in Type B watthour meters was jewel and recording train trouble. Jewel trouble was caused from wear in the ordinary way, and recording train trouble principally through gumming, as oil was used on the bearing in these trains, a practice which was afterwards discontinued.

Sangamo Meters, Type H.—Causes which would make a Type H watthour meter run fast on full load are the weakening of the permanent magnet or short-circuiting of some of the turns in the potential coil. The potential coil is thoroughly insulated between all turns and layers.



(a)
Sangamo Type H 2- and 3-phase Meter, for 5 to 100 amperes, and 110 to 550 volts, inclusive.

(c)
Sangamo Type H 2-phase, 4-wire Meter, for 5 to 100 amperes, and 110 to 550 volts, inclusive.



(b)
Sangamo Type H 2- and 3-phase Meter, for 150 amperes and over, 110 to 550 volts, inclusive, with current transformers.

(d)
Sangamo Type H 2- and 3-phase Meter, for all ratings of 1100 volts and above, with current and potential transformers.

FIG. 581.—External Connections of Sangamo. Type H (All Models), Polyphase Watthour Meters.

On light load, creeping may occur, due to initial over-compensation, or to change in the position of the light-load adjusting vane through vibration and loose adjustment.

Type H watthour meters could also run slow on light load due to change in the position of the light load adjustment in the same way as stated above for a possible tendency to run fast.

In general, these remarks also apply to the new model Type H meters.

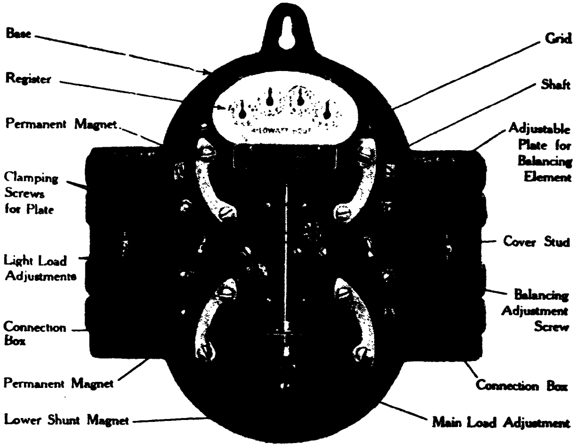


FIG. 582.—Annotated Internal View of Sangamo Type H (New Model) Polyphase Watthour Meter.

WESTINGHOUSE WATTHOUR METERS

Westinghouse Watthour Meters are manufactured by the Westinghouse Electric and Manufacturing Company. This company makes meters for both direct- and alternating-current service.

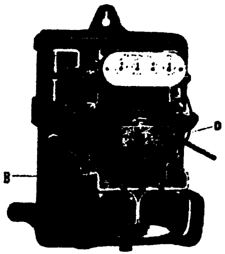


FIG. 593.—Westinghouse, Type DC, Plain, 2-wire, Direct-current Watthour Meter.

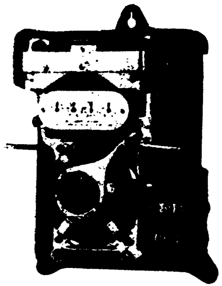


FIG. 594.—Westinghouse, Type DC, Sub A, 2-wire, Direct-current Watthour Meter.

The adjustment for light load is obtained by moving the compensating coil up or toward the armature to increase the speed of the disk. For full load moving the magnets in or toward the armature increases and moving them out decreases the meter speed.

DESCRIPTIONS OF VARIOUS DIRECT-CURRENT TYPES.—The various types of Westinghouse direct-current watthour meters are designated as the Type DC with suitable sub letters to indicate slight changes in construction and the Type CW-6 in which more extensive changes are included. The descriptions which follow will indicate the development of the direct-current watthour meters. For all types excepting the Type CW-6 the test constant is derived from two numbers which will be found on the interior of the cover, where the number of revolutions of the moving element corresponding to the stated number of kilowatthours is given. From these two values, the test constant can be found by multiplying the given number of kilowatthours by 3,600,000 and dividing the product by the given number of revolutions. The value so obtained is the test constant, and is the number of watt-seconds per revolution of the moving element.

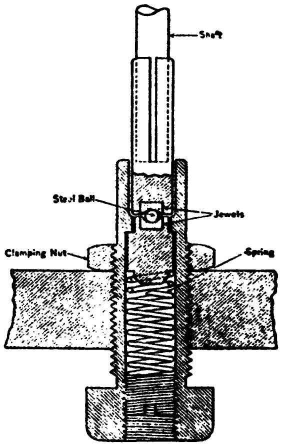


FIG. 595.—Cross-section of Lower Bearing of Westinghouse Direct-current Watthour Meters.

Type DC, Plain Meters.—These meters are of the commutator type for use on direct current. (Fig. 593.) The current winding in 2-wire meters of this type is divided into two independent coils located on opposite sides of the armature, one coil in the positive and the other coil in the negative side of the line circuit. The voltage circuit in the meter consists of a friction compensating coil, an armature, and a resistor or multiplier. The friction compensating coil end of the voltage circuit is connected to the negative terminal of the line circuit and the resistor end of the voltage circuit is connected to the positive terminal of the line circuit.

The terminals are on the sides, near the top. The line terminals are on the left-hand side of the meter case. The lower bearing of this meter consists of two sapphire jewels and a steel ball. (Fig. 595.) Instructions for metermen are placed on the inside of the cover of all Type DC, plain meters.

The 3-wire meter is very similar to the 2-wire meter. The current winding is divided into two independent coils, one in each of the outside lines of the 3-wire circuit. The resistor end of the voltage circuit is brought to a separate terminal for connection to the neutral line outside of the meter. The Type DC, plain meter, was manufactured in ratings from 5 to 100 amperes.

Type DC, Sub A Meters.—This is a commutator type meter. In 2-wire meters the current coils are connected to the positive side of the line circuit. The voltage circuit in the meter consists of a friction compensating coil, an armature, and a resistor. The friction compensating coil end of the voltage circuit is connected to the positive terminal of the line circuit and the resistor end of the voltage circuit is connected to the negative terminal of the line circuit.

The friction compensating coil has two movements,—one toward or away from the armature shaft, the other up or down in a plane parallel to the armature shaft.

The disk and permanent or drag magnets are at the top of the meter. The terminals are on the sides, near the bottom, of the meter case. The line terminals are on the left-hand side. (Fig. 594.)

The lower bearing of this meter consists of two sapphire jewels and a steel ball.

The 3-wire meter is similar with the exception that the current winding is divided into two independent coils, one for each of the outside lines of the 3-wire circuit. The resistor end of the voltage circuit is brought to a separate terminal for making connection to the neutral line outside of the meter. The above description applies to meters from 5 to 75 amperes rating.

In 2-wire meters of 100 to 450 amperes rating the positive side only of the line circuit is taken through the meter and the terminals are in the form of cables extending from the bottom of the meter case.

Three-wire meters of 100 to 300 amperes rating differ only in the terminals which are in the form of cables extending from the sides of the meter case.

Values of test constants for various types and ratings of Westinghouse direct-current watthour meters.—For all types and ratings of Westinghouse direct-current watthour meters, where V = voltage marked on the meter, and I = amperes marked on the meter, the test constant, $K_t = V \times I \times 2.4$.

When the voltage marking of 3-wire meters covers both the voltage between the neutral wire and the outer wires, and the voltage between the outer wires, such as 100-200 volts, V = the voltage between the outer wires.

For type CW-6 meters the test constant is in watthours and is therefore also the watthour constant.

External and Internal Connections for Westinghouse Direct-Current Watthour Meters

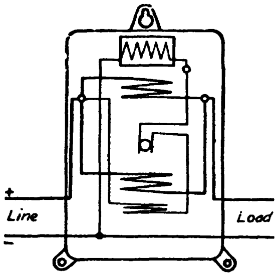


FIG. 596.—Direct-current, 2-wire, Type DC, Sub A, 5-15 Amperes.

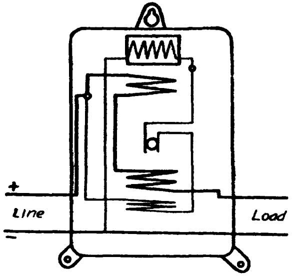


FIG. 597.—Direct-current, 2-wire, Type DC, Sub A, 15-75 Amperes.

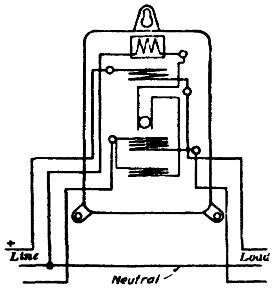


FIG. 598.—Direct-current, 3-wire, Type DC, Sub A, 5-75 Amperes, Type DC, Sub A, 100-300 Amperes.

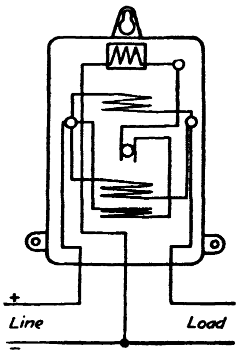


FIG. 599.—Direct-current, 2-wire, Type DC, Sub A, 100-450 Amperes.

Data from 1923 edition of Handbook for Electrical Metermen

Type CW-6 Direct-current Meters.—The current coils of 2-wire meters are in the positive side of the line circuit. The voltage circuit of the meter consists of the armature and the friction compensating coil. The resistance necessary for the voltage circuit is contained in the friction compensating coil, a portion of the winding being reversed on itself. The armature end of the voltage circuit is connected to the positive terminal of the line circuit; the friction compensating coil end of the voltage circuit is connected to the negative terminal of the line circuit.

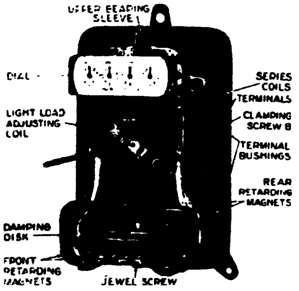


FIG. 600.—Westinghouse, Type CW-6, 2-wire Direct-current Watthour Meter. Cover Removed.

The friction compensating coil has two movements, one toward or away from the armature shaft, and the other up and down in a plane parallel to the armature shaft.

The disk and permanent or drag magnets are at the bottom of the meter.

The terminals are on the sides of the meter case.

The lower bearing of all standard Type CW-6 meters is a sapphire jewel and ball bearing, but pivot bearings are supplied when desired. Instructions for metermen are placed on the inside of the cover and also on the back of the meter (Fig. 600).

The 3-wire meter is similar with the exception that the current winding is divided into two separate coils, one in each of the outside lines of the three-wire circuit. The friction compensation coil end of the potential circuit is brought to a separate terminal for connection to the neutral on the outside of the meter.

The internal and external connections for these direct-current types of watthour meters are given in Figs. 596 to 599 and from 601 to 603.

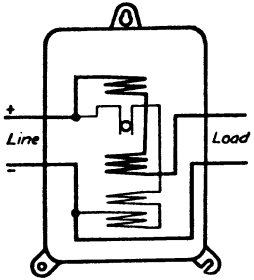


FIG. 601.—Direct-current, 2-wire, Type CW-6, 5-15 Amperes.

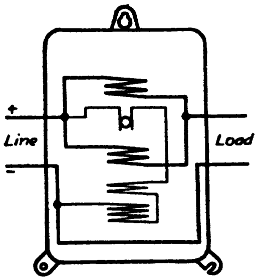


FIG. 602.—Direct-current, 2-wire, Type CW-6, 25-50 Amperes.

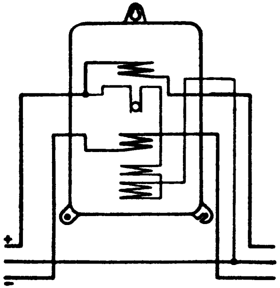


FIG. 603.—Direct-current, 3-wire, Type CW-6, 5-50 Amperes.

External and Internal Connections for Westinghouse, Direct-current Watthour Meters.

Descriptions of Westinghouse Alternating-current Watthour Meters.—The Westinghouse induction watthour meter for alternating-current circuits is in principle an induction motor generator provided with a suitable registering mechanism.

General Construction.—Rotation of the moving element or disk is obtained through the shifting field, produced by the interaction of the flux from the shunt and series field electromagnets.

Westinghouse induction type meters are provided with the usual type of registering mechanism consisting of circular graduated dials and proper gearing.

Bearings.—The bearings used in the Type B, C and OA watthour meters are shown in cross section in Fig. 604.

The lower bearing consists of a steel ball resting between two sapphire cup jewels, one fixed in the end of the bearing screw and the other mounted in a removable sleeve on the end of the shaft. Owing to the minute gyrations of the shaft the ball has a rolling action.

The upper bearing is only a guide bearing to keep the shaft in a vertical position, and is subject to virtually no pressure. It consists of a steel pin fastened to a removable screw and projecting down into a bushing in a recess drilled in the shaft. The bottom of this recess is filled with chamois disks saturated with watch oil. A film of oil is maintained around the pin by capillary action.

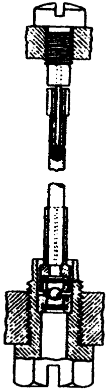


FIG. 604.—Cross-section of Bearings of Type OA Watthour Meters.

Friction Compensating Adjustment.—Friction compensation, or light-load adjustment, in the Type C and OA meters, is accomplished by slightly unbalancing the two legs of the shunt magnetic circuit. To do this a short circuit loop is placed in each air gap, and means are provided for adjusting the position of the loops so that one loop will enclose more of the flux than the other loop, and thus produce a slight rotative torque. This torque depends on voltage alone, which is practically constant, and is entirely independent of the load.

Adjustment is accomplished by means of either of two screws. It is clamped when adjusted by means of a set screw.

The power-factor adjustment consists of a short circuited loop enclosing part or all of the field flux produced by the current in the potential coil. By shifting the position of the short circuited loop, the lag may be so adjusted that the proper phase relation is obtained.

Miscellaneous Features.—The case and cover are dust and bug proof, and are provided with means for sealing. Terminal chambers are so arranged that the cover of the meter element need not be removed when making connections.

Types.—Westinghouse induction watthour meters have passed through various stages of development and the different changes in construction or design are indicated by form letters. The significance of these letters is explained in the following descriptions:

Round Type, Single-phase Induction Meters, Two-wire.—The electromagnet of this type of meter is made up with one coil for the current element, and a potential coil in two sections with an impedance coil in series for the potential element.

Full-load adjustment is made by moving the permanent magnets from, or toward the disk shaft. Moving the magnets from the shaft increases the speed of the meter. Moving the magnets toward the shaft decreases the speed of the meter.

FIG. 605.—External View of Westinghouse, Round Type, Single-phase, Induction Watthour Meter.

The light-load adjustment is made by varying the resistance of a short circuited coil on the right-hand side of the electromagnets.

Power-factor adjustment is made by varying the resistance of a small coil on the left side of the electromagnet.

The terminals are on the back of the meter.

Three-wire Meters.—This meter is similar to the two-wire. The three-wire circuit measurement is obtained by means of a three-wire current transformer.

General Data for Round Type Meters.—The Westinghouse Round Type watthour meter was designed for house service for use upon alternating current, two- and three-wire circuits;—two-wire in ratings of 5, 10, 20, 40 and 80 amperes, 100, 200 and 400 volts; three-wire, in ratings of 5, 10, 20, and 40 amperes, 100-200, 200-400 volts. The single-phase meter was produced in June, 1898. The meter is illustrated in Fig. 605.

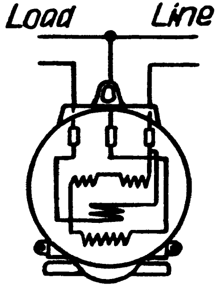


FIG. 606.—Diagram of Connections, Westinghouse Round Type, Single-phase, 2-wire Meter.

Type A, Single-phase Induction Meters.—*Two-wire Meters.*—The electromagnet is made up of one current coil for the current element and a potential coil in two sections with an impedance coil in series for the potential element.

Full-load adjustment is made by varying the position of the permanent magnets the same as in the Round Type meters.

Light-load adjustment is made by the movement of a slide resistance, which is located on the electromagnet near the bottom of the meter.

The power-factor adjustment is made by varying the resistance of a short circuited coil on the left-hand side of the electromagnet.

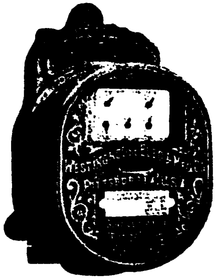


FIG. 607.—External view of Type A, Westinghouse, Single-phase, 3-wire, Induction Watthour Meter.

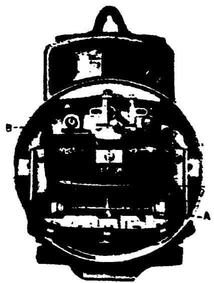
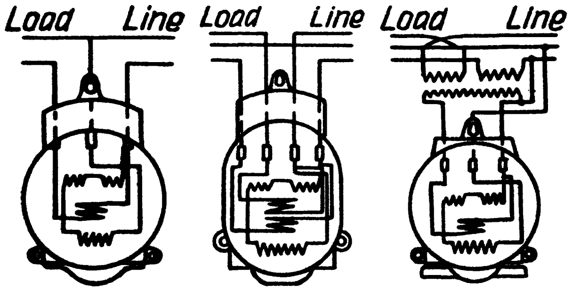


FIG. 608.—Westinghouse, Type A, Single-phase, 2-wire, Induction Watthour Meter, Cover and Register Removed.

Three-wire Meters.—This meter is similar to the two-wire with the exception of the current winding, which consists of two separate, but interlaced coils.

Full-load, light-load and power-factor adjustments are the same as for the two-wire meter.

The meter has four terminals located in a separate terminal chamber at the top of the meter.



a
2-wire

b
3-Wire

c
3-Wire with 3-Wire Current Transformer

FIG. 609.—Diagrams of Connections for Westinghouse, Type A, Single-phase Watthour Meters.

Three-wire Meter with Three-wire Current Transformers.—This meter is similar to a two-wire meter with the exception that the measurement of the three-wire circuit is obtained by the use of a three-wire current transformer.

General Data for Type A Meters.—The Westinghouse Type A watthour meter was designed for house service for use upon alternating-current, two- and three-wire circuits; the two-wire in ratings of 5, 10, 20, 40 and 80 amperes, 100-200 and 400 volts; the three-wire in ratings of 5, 10, 20 and 40 amperes, 100-200, 200-400 volts. The single-phase meter was produced in January, 1903. The moving element had the ball bearing feature. (Figs. 607 and 608.)

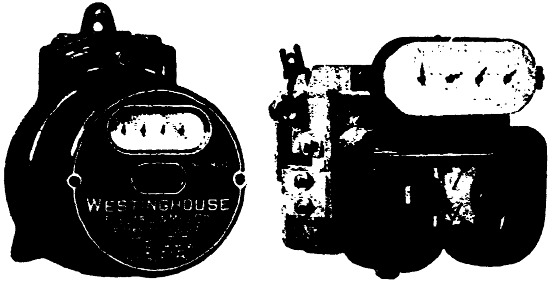


FIG. 610.—Westinghouse, Type B, Single-phase, 2-wire Induction Watthour Meter.

Type B, Single-phase Induction Meters.—*Two-wire.*—The electromagnet of this meter consists of the current coil mounted on two poles, one half the winding on each pole, and a potential coil mounted on a single pole. No separate impedance coil is used in the potential circuit.

Full-load adjustment is made by varying the position of the permanent magnets. Moving the magnets away from the disk-shaft decreases the speed of the meter. Moving the magnets toward the disk-shaft increases the speed of the meter.

Light-load adjustment is obtained by varying the position of a short-circuit loop located in one of the leakage gaps of the potential electromagnets.

Power-factor adjustment is obtained by varying the position of a short-circuit loop placed over the tip of the potential pole.

The meter has four terminals located in the terminal chamber at the top.

Three-wire Meters.—These are similar to the two-wire, except that the current coil is divided into two interlaced and independent circuits.

General Data for Type B Meters.—The Westinghouse Type B and prepayment watthour meters were designed for house service use on alternating-current, two- and three-wire, single-phase circuits; the two-wire Type B in ratings of 5, 10, 20, 40 and 80 amperes, 100, 200 and 400 volts; the three-wire Type B in ratings of 5, 10, 20 and 40 amperes, 100-200, 200-400 volts. These meters have a separate terminal chamber at the top and are equipped with metal or glass covers. They were produced in December, 1905. The two-wire prepayment type was built in ratings of 5, 10, 15 and 20 amperes, 100 and 200 volts, and the three-wire in ratings of 5, 10, 15 and 20 amperes, 100-200 volts. They were produced in January, 1906.

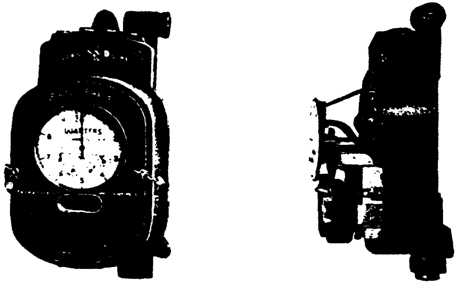


FIG. 611.—Westinghouse, Type B, Prepayment, Single-phase, 2-wire, Induction Watthour Meter.

Type B, Prepayment Meters.—The meter element is the same a that for the regular Type B meter.

The prepayment mechanism is so arranged that when a coin is deposited in the meter the fact is indicated on the large dial. When the energy paid for has been consumed a contact operated through a small differential gear is closed and the service discontinued by an electrically operated switch (Fig. 611).

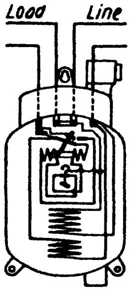


FIG. 612.—Connections of Single-phase Type B, 2-wire Prepayment Watthour Meter.

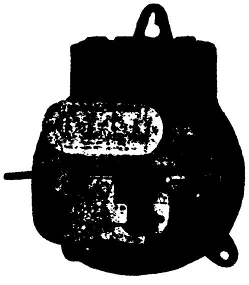


FIG. 613.—Westinghouse, Type C, Sub B, C, D, E and F, Single-phase, 2-wire, Induction Watthour Meter.

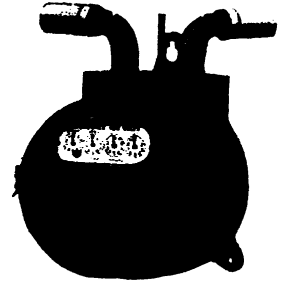


FIG. 614.—Westinghouse, Type C, Sub G, Single-phase, 2-wire, Induction Watthour Meter (100 Amperes or over).

Type C, Single-phase Induction Meters.—*Two-wire, Plain and Sub A.*—The electromagnet consists of a current coil mounted on two poles, one-half the winding on each pole, and a potential coil mounted on a single pole. No separate impedance coil is used in the potential circuit. The iron laminations in the current windings are not interlaced with the laminations of the potential winding.

Full-load adjustment is made by varying the position of the permanent magnets. Moving the magnets away from the disk-shaft decreases the speed of the meter and moving the magnets toward the disk-shaft increases the speed of the meter.

The light-load adjustment consists of two short-circuited loops, one in each of the two leakage gaps of the voltage electromagnet.

Power-factor adjustment is obtained by varying the position (up or down) of a short circuit loop on the tip of the potential pole.

The meter has four terminals which are in a separate terminal chamber recessed in the upper sides of the meter case (Fig. 618).

Three-wire, Plain and Sub A Meters.—These meters are the same as the two-wire meters with the exception that the current circuit is divided into two interlaced and independent windings.

Two-wire, Sub B, C, D, E, F and G Meters, 5 to 80 Amperes.—For the Sub B and Sub C the electromagnet is similar to that of Type C Plain.

For Sub D, E, F and G the electromagnet is similar to that of the Type C Plain, but the laminations in the current and potential coils are interlaced.

Full-load, light-load and power-factor adjustments are similar to those of the Plain and Sub A meters. The later Subs provide for more convenient adjustments. In the Sub E Meters a micrometer adjustment for light load was added, and in the Sub F a similar adjustment was added for full load. The power-factor adjustment in later subs consists of a short-circuited coil on the potential pole tip.

The terminal chamber is at the top of the meter and has four terminals (Fig. 613).

Three-wire, Sub B, C, D, E, F and G Meters, 5 to 40 Amperes. These meters are the same as the two-wire, except that the current winding is divided into two interlaced and independent coils.

Later productions of Sub F and G are provided with an extra potential terminal in the terminal chamber, the purpose of which is to facilitate testing.

FIG. 615.—Adjustment of Type C Sub G and F.

FIG. 616.—Adjustment of Type C Sub E.

Two-wire, Sub E, F and G Meters, 100 to 300 Amperes.—The electromagnet and its adjustments are similar to that of the meter of low rating. The current and potential laminations are not interlaced. The meter has three terminals leading from the top of the case. The middle lead is a potential lead, which in service is connected to the other side of the line.

Three-wire, Sub E, F and G Meters, 60 to 150 Amperes.—The electromagnet is similar to the two-wire heavy-current meter. The current coils are independent of each other, are not interlaced, and are provided with special laminations which are interlaced with the laminations of the potential coil.

The meter has five terminals extending from the top of the meter. The potential coil is wound for placing across the outside lines of the three-wire circuit. The middle lead is one end of the potential coil brought out for test purposes.

General Data for Type C Meters.—The Westinghouse Type C watthour meter was designed for house service for use upon alternating-current, two-wire single-phase, and polyphase circuits, in ratings of 5, 10, 15, 20, 30, 40, 60, 80, 100, 120, 150, 200 and 300 amperes, 100, 200, 400 and 500 volts, the two-wire meter being produced in November, 1906, and the polyphase meter in February, 1906. The three-wire single-phase meter was built in ratings of 5, 10, 15, 20, 30, 40, 60, 80, 120, and 150 amperes, 100-200, 200-400 volts, in November, 1906.

Adjustment of Type C Sub G and F Meters.—For light-load adjustments, slacken screw D (Fig. 615) and turn screw E in direction indicated by letters "F" or "S" to increase or decrease speed. For full-load adjustment, slacken screws A and adjust with screws B on both sides of meter; moving the magnets in increases, and moving the magnets out decreases, the meter speed. For frequency, to change 133-cycle meters for use on 60-cycles, twist together the ends of the compensating coil, located under the shield casting, to the point shown by condition of the wire.

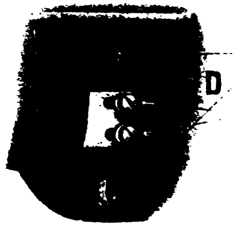


FIG. 617.—Adjustment of Type C Sub D Meters.

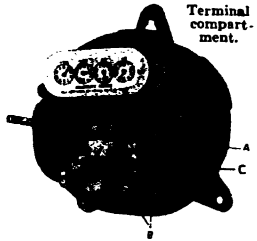
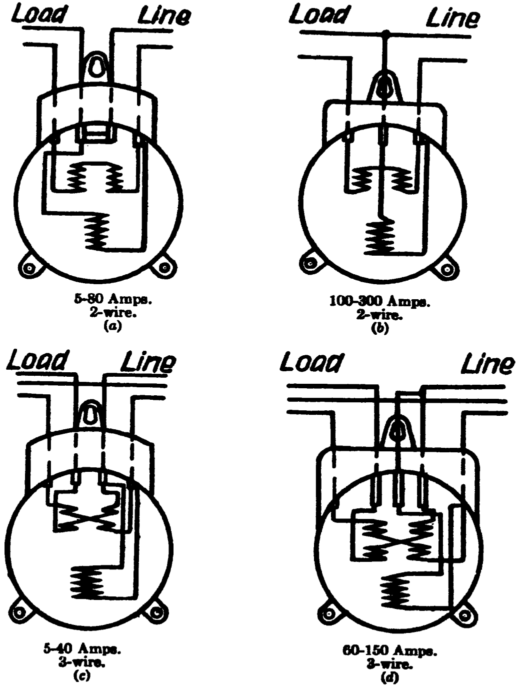


FIG. 618.—Adjustment of Type C, Sub C, B, A and Plain Meters.

Adjustment of Type C Sub E.—For light-load, slacken screw D (Fig. 616) and turn screw E in direction indicated by letters "F" or "S" to increase or decrease speed. For full load, move the magnets in to increase and out to decrease the meter speed. For frequency, to change 133-cycle meters for use on 60 cycles, twist together the ends of the compensating coil, located under the shield casting, to the point shown by condition of the wire.



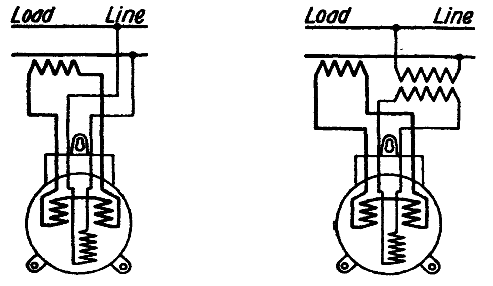
5-80 Amps. 2-wire. (a)

100-300 Amps. 2-wire. (b)

5-40 Amps. 3-wire. (c)

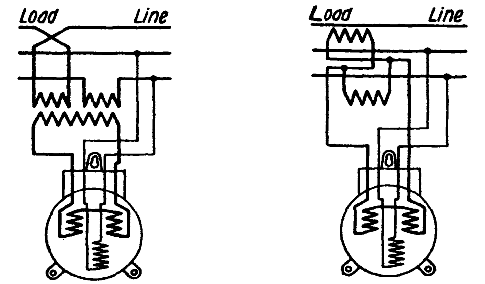
60-150 Amps. 3-wire. (d)

FIG. 619.—Diagrams of Connections, Westinghouse, Type C, Single-phase House Type Meters, Sub B to G.



2-wire with Current Transformer.
(e)

2-wire with Current and Voltage Transformers.
(f)



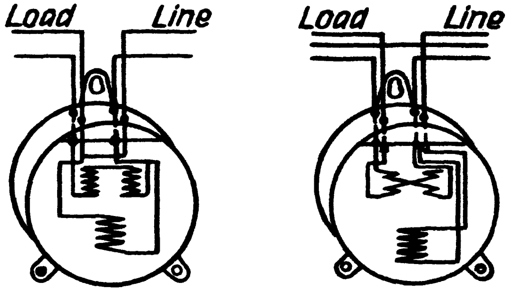
3-wire with 3-wire Current Transformer.
(g)

3-wire with Two Standard Current Transformers.
(h)

FIG. 620.—Diagrams of Connections, Westinghouse, Type C, Single-phase House Type Meters, Sub B to G.

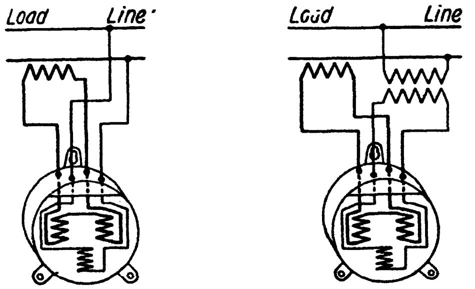
Adjustment of Type C Sub D Meters.—For light-load adjustment, slacken screw D (Fig. 617) and move the lever at bottom of the meter to the left or right, to increase or decrease the speed. For full-load adjustment, move the magnets in, to increase, and out to decrease, the meter speed. For frequency, to change 133-cycle meters for use on 60 cycles, twist together the ends of the compensating coil, located under the shield casting, to the point shown by condition of the wire.

NOTE:—Connections for bottom-connected and left-hand feed meters are similar to type OA, Fig. 632.



5-80 Amps.
2-wire.
(a)

5-40 Amps.
3-wire.
(b)

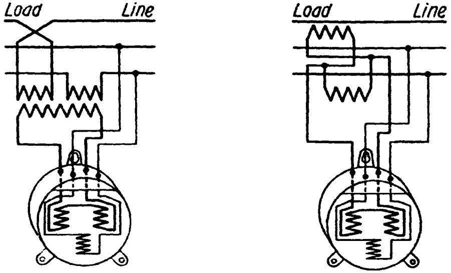


2-wire with Current Transformer.
(c)

2-wire with Current and Voltage Transformers
(d)

FIG. 621.—Diagrams of Connections, Westinghouse, Type C, Single-phase House Type Meters, Sub B to G.

Adjustment of Type C Sub C, B, A, and Plain Meters.—For light-load adjustment, slacken screw B (Fig. 618) and move short-circuited loop A up or down to increase or decrease the speed. For full-load adjustment, move the magnets in to increase, and out to decrease the disk speed. For power-factor adjustment, lower the power-factor adjustment loop to increase, and raise it to decrease the power-factor compensation. For frequency, to change 125 or 133-cycle meter for use on 60-cycles, remove the insulating washer under the power-factor adjustment loop and clamp the copper strip against the supporting frame by means of the holding screw.



3-wire with 3-wire Current Transformer.
(e)

3-wire with Standard Current Transformers.
(f)

FIG. 622.—Diagrams of Connections, Westinghouse, Type C, Single-phase House Service Meters, Sub A and Plain.

Type OA, Single-phase, Induction Meters.—In the development of Type OA meters various changes have been made in the design from time to time. The original Type OA meters were known as plain meters and the style numbers, as given on the rating plates, consist only of a number. Each set of changes has been indicated by the addition of a sub letter to the style number. The various changes are given in the following descriptions.

Plain Meters.—This is the earliest design of the Type OA single-phase meter (Fig. 623). The sub-gear train has but a single reduction between the main shaft and worm, and the steel ball bearing in the sub-gear train is not lubricated.

The electromagnet of these meters is, in general, similar to that of the Type C. The shape of the laminations is somewhat different and in the 60-cycle meters the amount of iron is less.

The full-load adjustment is similar to that of the Type C.

The light-load adjustment is made by the movement of a micrometer screw on the right side of the meter.

The power-factor adjustment is obtained by the use of a short-circuited loop on the tip of the voltage electromagnet.

The three-wire meters are similar to the two-wire except that the current coil is divided into two independent windings.

Plain meters are made with top or bottom terminals and with terminal chambers arranged for either right- or left-hand feed.

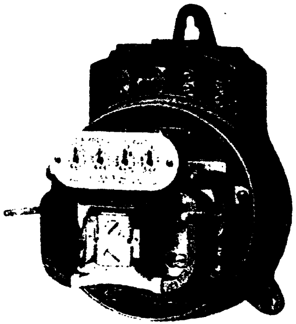


FIG. 623.—Westinghouse, Type OA, Single-phase, 2-wire, Induction Watthour Meter, with Top Terminals.

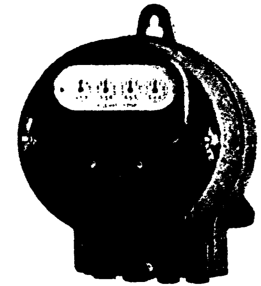


FIG. 624.—External View of Type OA, Sub D, Westinghouse, Single-phase, 2-wire, Induction Watthour Meter, with Bottom Terminals.

Sub A Meters.—These meters are similar to the plain type except that the sub-gear train has two reductions between the main shaft and worm, and the steel ball bearing in the sub-gear train is lubricated.

Sub B Meters.—The sub B meters differ from the sub A meters in the following details: the sub-gear train has jewels added for the lower bearing; the gear wheel shaft is of brass instead of steel; no rating is given on the dial face; the laminations of the electromagnet are made of one piece, making the electromagnet smaller and the internal connections more accessible; the light-load adjustment is made accessible from the front of the meter.

Sub C Meters.—These meters are similar to the sub B but have an additional feature consisting of a micrometer full-load adjustment.

Sub D Meters.—In the sub D meters the electromagnet has a greater number of laminations than in the sub C.

Sub E Meters.—The sub E meters have a slightly different electromagnet from the sub D. In general, the parts are interchangeable with parts of sub F, D, C and B meters.

Sub F Meters.—These superseded the sub E meters. They are furnished with either metal or glass covers and differ from the sub E meters in having a nickel finish on the gear train and in having a slightly different electromagnet. In general the parts are interchangeable with parts of the sub E, D, C and B meters.

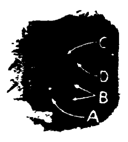


FIG 625.—Adjustment of Type OA, Sub F, E, D and C Meters.

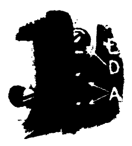


FIG. 626.—Adjustment of Type OA, Sub B Meter.

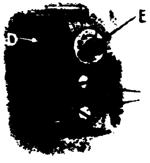


FIG. 627.—Adjustment of Type OA, Sub A and Plain Meters.

Adjustment of Type OA, Subs C, D, E and F Meters.—For light-load adjustment, loosen screw D (Fig. 625) and turn screw C in direction indicated by "F" or "S" on bracket to increase or decrease speed. Secure the adjustment by tightening screw D. For full-load adjustment, loosen screws B and adjust with screw A on both sides of meter. Moving the magnets in increases, and moving the magnets out decreases, the meter speed.

Adjustment of Type OA, Sub B Meter.—For light-load adjustment, loosen screw D (Fig. 626) and turn screw E in direction indicated by arrow "F" or "S" on casting, to increase or decrease speed. Secure the adjustment by tightening screw D. For full-load adjustment, moving the magnets in increases, and moving the magnets out decreases, the meter speed.

Adjustment of Type OA, Sub A and Plain Meters.—For light-load adjustment, loosen screw D (Fig. 627) and turn screw E in the direction indicated by the arrow "F" and "S" shown on the disk mounted on the screw. Secure the adjustment by tightening the screw D. For full-load adjustment, move the magnets in to increase, and out to decrease, the meter speed.

Connections of Westinghouse Type OA Meters.

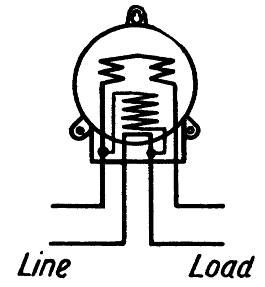


FIG. 628.—Single-phase, 2-wire, Type OA, Sub A, Sub B, Sub C, Sub D, Sub E and Sub F, and Type RO, 5-80 Amperes (Left Hand Feed).

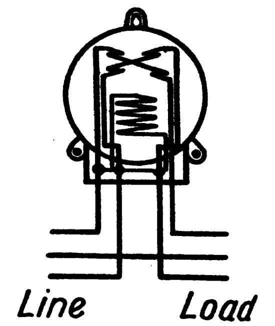


FIG. 629.—Single-phase, 3-wire, Type OA, Sub A, Sub B, Sub C, Sub D and Type RO, 5-60 Amperes (Left Hand Feed).

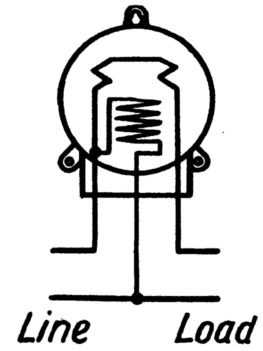


FIG. 630.—Single-phase, 2-wire, Type OA, Sub A, 100-300 Amperes.

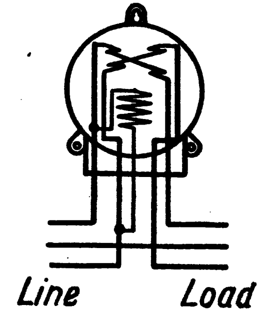
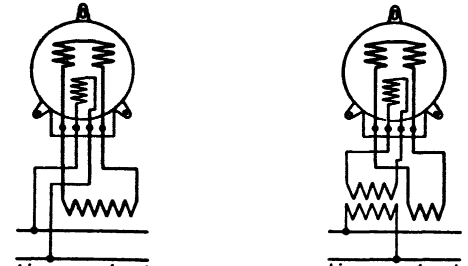
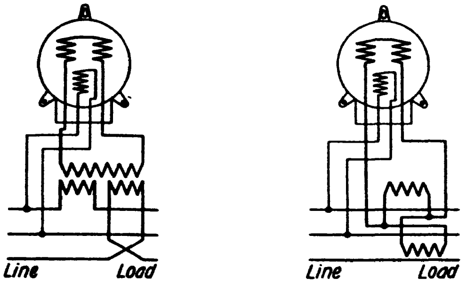


FIG. 631.—Single-phase, 3-wire, Type OA, Sub A, 75-150 Amperes.



2-wire with Current Transformer.
a

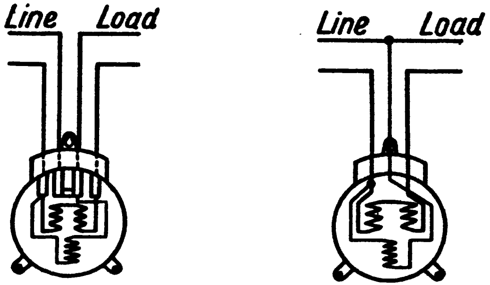
2-wire with Current and Voltage Transformers.
b



3-wire with 3-wire Current Transformer.
c

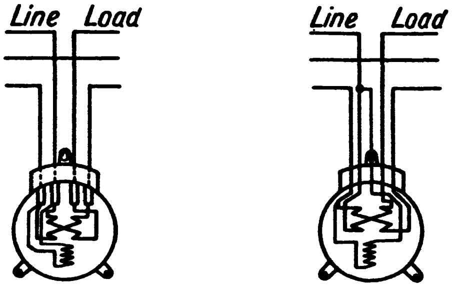
3-wire with Standard Current Transformers.
d

FIG. 632.—Diagrams of Connections for Westinghouse, Type OA Sub F, E, D, C, or B Single-phase Meters.



5-80 Amps.
2-wire.
a

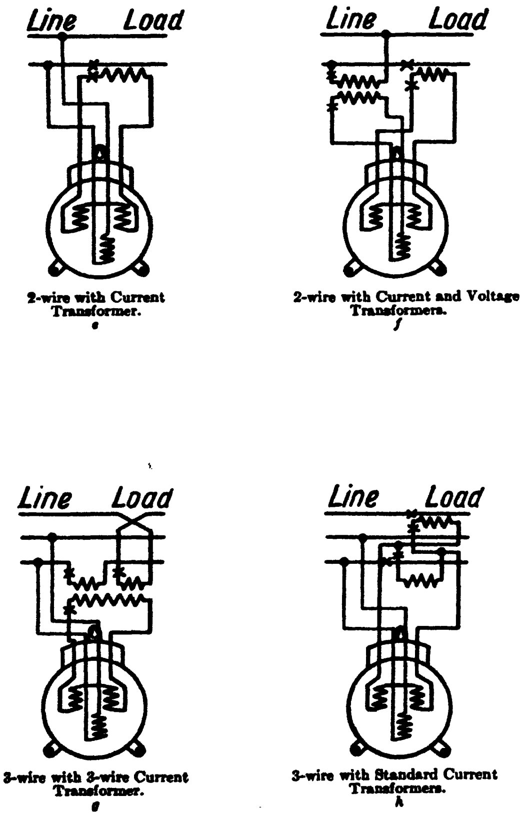
100-300 Amps.
2-wire.
b



5-60 Amps.
3-wire.
c

80-150 Amps.
3-wire.
d

FIG. 633.—Diagrams of Connections for Westinghouse Type OA Sub A and Plain Single-phase Meters.



2-wire with Current Transformer.
e

2-wire with Current and Voltage Transformers.
f

3-wire with 3-wire Current Transformer.
g

3-wire with Standard Current Transformers.
h

FIG. 634.—Diagrams of Connections for Westinghouse, Type OA Sub A and Plain Single-phase Meters.

Type OA, Prepayment, Single-phase Meters.—*Two-wire Meters.*—This meter is built for ratings from 5 to 25 amperes, for rates of 5 cents to 20 cents, and for 25-cent coins. The prepayment mechanism and the switch control are mechanically operated. The line switch is automatically closed by the hand operated lever at the time of the insertion of the first coin and remains closed until the energy paid for has been delivered. Ten coins can be inserted successively at one time.

The electromagnet is similar to that of the OA sub A meter (Fig. 636).

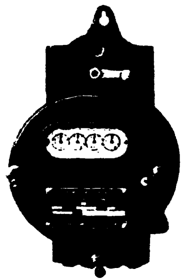


FIG. 635.—External View of Type OA, Westinghouse Single-phase Prepayment Meter.

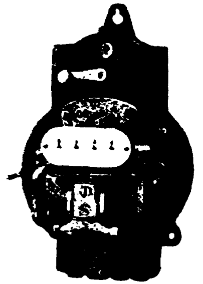


FIG. 636.—Cut-out Switch and Prepayment Escapement; Type OA, Westinghouse, Single-phase, Prepayment Meter

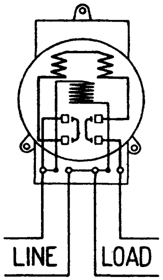
With bottom terminals, left-hand feed terminals to line, and right-hand to load, is standard.

Three-wire Meters.—These meters are similar to the two-wire meters. The current coil and the line switch are divided into two independent parts.

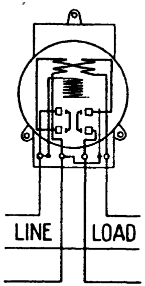
The Type OA, Single-phase, Prepayment Meter was produced September, 1914.

Type OA Prepayment Attachment.—A modification of the Type OA prepayment attachment is shown in Fig. 639.

The prepayment attachment mechanism is entirely mechanical. By placing a quarter in the top of the coin chamber and by turning the knob in the direction of the arrow, the meter is made ready to give electrical service as required by the customer. This operation of the knob winds a clock spring which is unwound by gears at a speed depending upon the rate per kilowatt hour for which the attachment is furnished. When the spring is completely unwound a quick-break switch is automatically opened and the customer is without power until additional quarters have been placed in the



2-wire
FIG. 637.—Diagrams of Connections, Type OA, Prepayment Meters.



3-wire
FIG. 638.—Diagrams of Connections, Type OA, Prepayment Meters.

coin mechanism. The attachment can be supplied for rates of 4 to 25 cents per kilowatthour (full cents only).

The attachment is designed to receive quarters in any number up to sixteen at one time, provided that the customer has no quarters already to his credit. A pointer always indicates on a marked dial the number of quarters that remain to the credit of the customer.

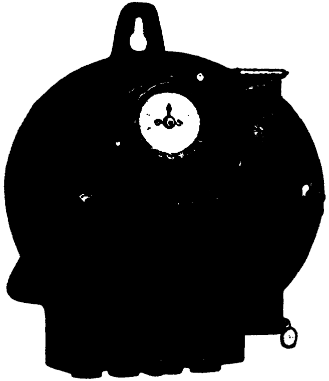


FIG. 639.—Type OA Watthour Meter with Prepayment Attachment.

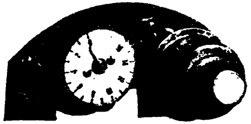


FIG. 640.—Type OA Prepayment Attachment without Integrating Dials.

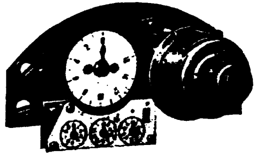


FIG. 641—Type OA Prepayment Attachment with Integrating Dials.

When the customer has sixteen coins to his credit, the sixteenth coin automatically closes the coin chamber so that no more coins can be placed in the mechanism until electrical energy equal to the value of one or more quarters has been used. The coin chamber will hold approximately twenty-five quarters.

With the aid of the scale marked on the cover (see Fig. 639) and surrounding the indicating dial, it is possible to determine the number of quarters that have been placed in the meter, by observing the position of the zero on the dial with reference to the numbers on the fixed scale on the cover. Knowing the number of quarters and the rate per kilowatthour, the number of kilowatthours can be determined. If it is not desirable to determine in this manner the kilowatthours used by the customer, the attachment can be supplied with a small three-dial register reading direct in kilowatthours. This register is shown in Fig. 641.

SPECIAL NOTE.—After April, 1915, all Westinghouse watthour meters were manufactured in the standard sizes as recommended by Meter Committees. These ratings are 5, 10, 15, 25, 50, 75, 100, 150 and 300 amperes, two-wire, and up to 150 ampere three-wire, and replace the 20, 40, 60, 80 and 120 ampere ratings formerly used.

Westinghouse Polyphase Meters.—Westinghouse polyphase watthour meters are in effect, combinations of two single-phase electrical elements, each acting upon a disk fixed to a single shaft. Registration of the meter is obtained upon a single register.

Round Type Polyphase Meters.—This is a two-element (two-disk, single-shaft) meter. The individual electromagnets and the adjustments of this meter are the same as for the single-phase meter. The terminals are on the back of the meter. This type was produced in July, 1899 (Fig. 642).

Type A, Polyphase Meters.—This is a two-element (two-disk, single-shaft) meter, similar in appearance to the Round Type polyphase, has the ball bearing and was produced in May, 1903. The individual magnets with their adjustments are similar to the electromagnets of the single-phase meter.

The meter has six terminals, three per element, located on the back of the meter.

Data from 1923 edition of Handbook for Electrical Metermen

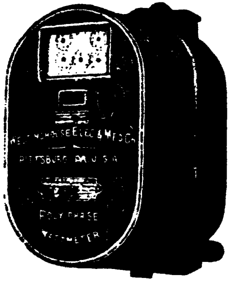


FIG. 642.—External View of Westinghouse, Round Type, Polyphase, Induction Watthour Meter.

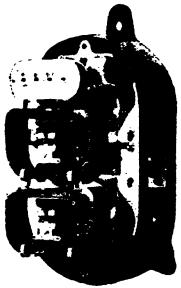
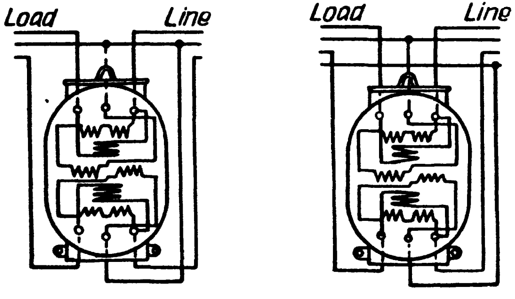


FIG. 643.—Westinghouse, Type C, Polyphase, Induction Watthour Meter.



3-wire
a

2-phase, 4-wire
b

FIG. 644.—Diagrams of Connections, Type A Polyphase Meters.

Type C, Polyphase Induction Meters.—*Plain, 5 to 80 Amperes.*—This is a two-element (two-disk, one-shaft) meter. The individual electromagnets with their adjustments are the same as for the single-phase meter, Type C, plain and sub A. The meter has three terminals per element, two on the right side and one on the left. Terminals are in a separate terminal chamber recessed in the sides of the case (Fig. 643).

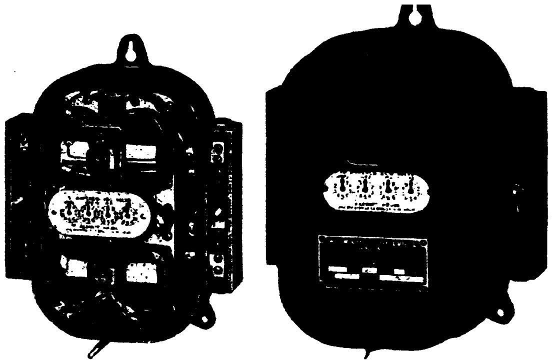


FIG. 645.—Westinghouse, Type C, Sub A and Sub B, Polyphase, Induction Watthour Meter.

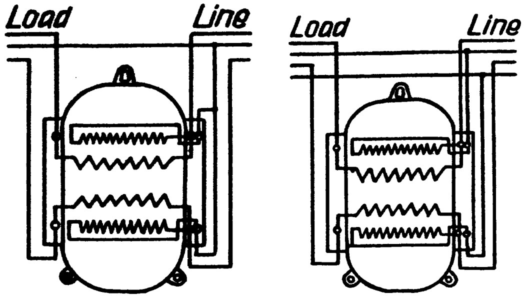
Sub A and B Meters, 5 to 80 Amp.—This is a two-element (two-disk, one-shaft) meter. The electromagnets and their adjustments are the same as for the single-phase, sub D to F, 5- to 80-ampere meters. The meter has side terminal chambers (Fig. 645).

Sub A and B Meters, 100 to 300 Amp.—The electromagnets and their adjustment are the same as for the electromagnets of the meters of low rating. The laminations in the current and potential coils are not interlaced. The terminal leads are on the sides, two current terminals on each side and two voltage, or potential, terminals on the right side.

Plain, Sub A and B Meters with Current and Potential Transformers.—These meters are similar to the 5-80 ampere (low-rating), polyphase meters, except that the voltage winding is entirely independent of the current terminals. The meters have four terminals per element.

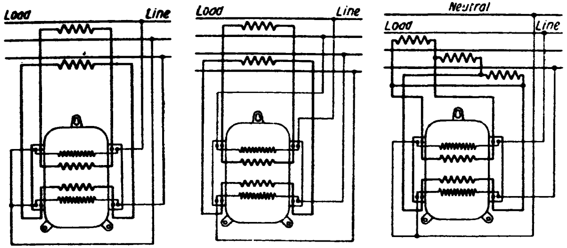
Three-phase, Four-wire, Sub A and B Meters, 5 to 40 Amp.—The electromagnets of this meter are the same as the electromagnets of the polyphase, sub A and B, 5- to 80-ampere rating, except that there is an additional interlaced current winding on each element. These additional windings on each element are connected in series, forming the current winding for the third current line. The potential coil is connected between outside wire and neutral or fourth wire. The meter has seven terminals.

Three-phase Meters with Current and Potential Transformers for Four-wire Circuits.—This meter is the same as the regular polyphase meter for transformer use. The three-phase measurement is obtained by the use of three current transformers and two potential transformers.



a
3-wire without Transformers.

b
2-phase, 4-wire without Transformers.



c
3-wire with Current Transformers.

d
2-phase, 4-wire with Current Transformers.

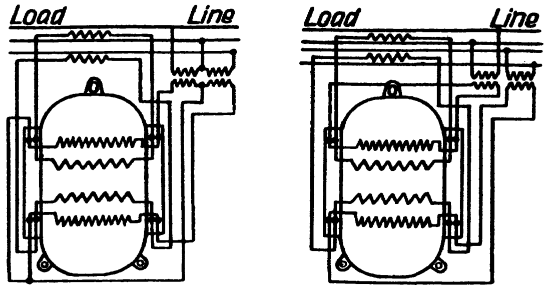
e
3-phase, 4-wire with Current Transformers.

FIG. 646.—Diagrams of Connections, Westinghouse Type C House Type Polyphase Meters.

Type OA, Polyphase Meter.—This meter, in general appearance, is similar to the Type C Polyphase. It is smaller, however, has a pressed zinc cover, and has its terminals in the side of the terminal chamber. The terminals are more accessible than those of the Type C.

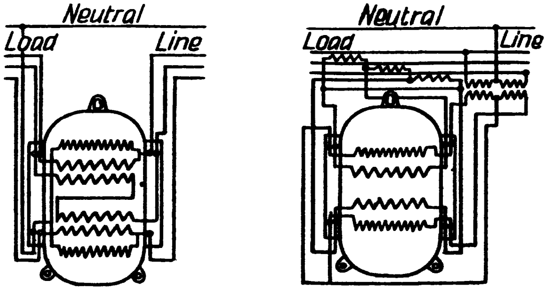
The electromagnets are similar to those used in the OA sub D meters. (Figs. 648, 649 and 650.)

The full-load and light-load adjustments are similar to those used in the OA sub D.



a
3-wire with Current and Voltage Transformers.

b
2-phase, 4-wire with Current and Voltage Transformers.



c
3-phase, 4-wire without Transformers.

d
3-phase, 4-wire, with Current and Voltage Transformers.

FIG. 647.—Diagrams of Connections, Type C House Type Polyphase Meters.
Note:—For left-hand feed see Fig. 653 (OA).

Sub B Polyphase meters have electromagnet adjustment for balancing phases. This adjustment is made by loosening screws A (Fig. 650) and moving plate B up or down with a screw driver as shown in Fig. 650. Moving the plate B up increases the torque of the upper element and decreases the torque of the lower element. Moving the plate down increases the torque of the lower element and decreases the torque of the upper element.

Meters of Serial Numbers below 2,017,680, made before December 27, 1915, had their common shunt connection brought out on the line side of the meter instead of on the load side as at present.

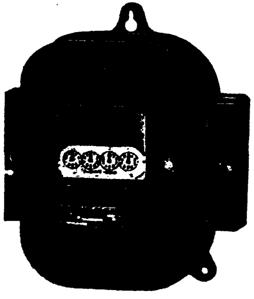


FIG. 648.—External View of Type OA, Westinghouse, Polyphase, Watthour Meter.

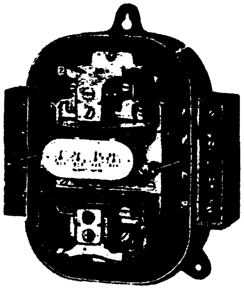


FIG. 649.—Internal View of Type OA, Westinghouse, Polyphase, Watthour Meter.

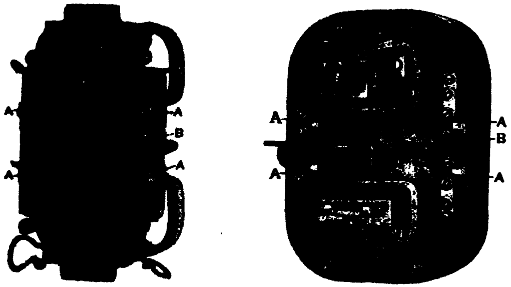
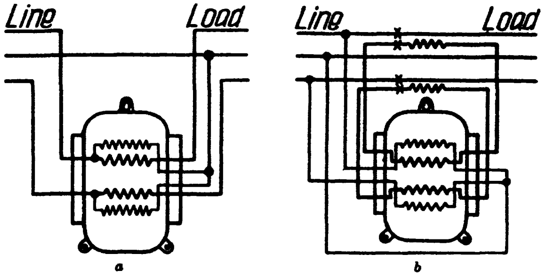


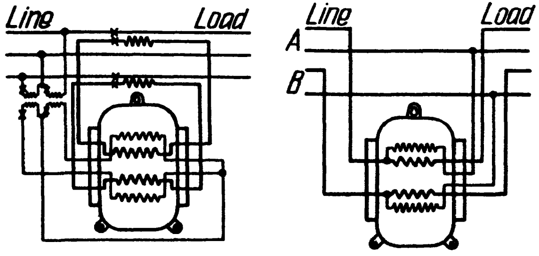
FIG. 650.—Rear and Front View of OA Polyphase Frame.



a
2- or 3-phase, 3-wire without Transformers.

b
2- or 3-phase, 3-wire with Current Transformers.

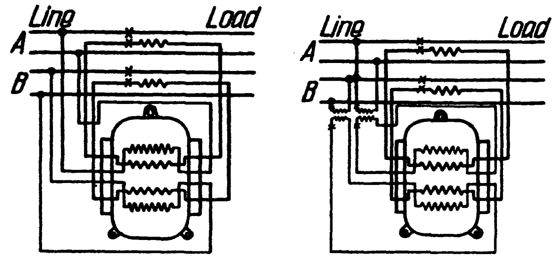
Fig. 651.—Diagrams of Connections, Westinghouse Type OA, Polyphase Meters.



a
2- or 3-phase, 3-wire with Current and Voltage Transformers

b
2-phase, 4-wire without Transformers

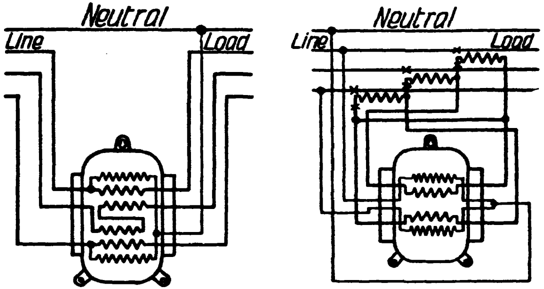
Fig. 652.—Diagrams of Connections, Westinghouse Type OA, Polyphase Meters.



c
2-phase, 4-wire
with Current
Transformers

d
2-phase, 4-wire
with Current and
Voltage Transformers

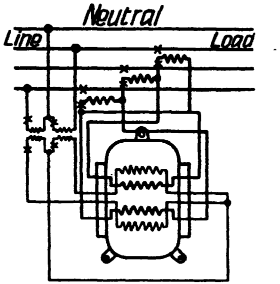
FIG. 652.—(Cont'd) Diagrams of Connections, Westinghouse, Type OA, Polyphase Meters.



a
3-phase, 4-wire
without Transformers

b
3-phase, 4-wire, with
Current Transformers

FIG. 653.—Diagrams of Connections, Westinghouse, Type OA, Polyphase Meters.



e
3-phase, 4-wire with
Current and Voltage Transformers

FIG. 653. (Cont'd) Diagrams of Connections, Westinghouse, Type OA, Polyphase Meters.

FIG. 654.—Westinghouse, Type C, Switchboard Polyphase Induction Watthour Meter. Rectangular Pattern.

The glass-cover switchboard watthour meter has a rectangular case, and in the latest model is rear-connected only. The meter can be furnished for any rating listed for the metal-cover meter.

Tables of test constants, gear ratios, etc., and connection diagrams follow.

Type C Switchboard Watthour Meters.—The Westinghouse Type C switchboard watthour meter contains electromagnets similar to those used in the Type C house service watthour meter. The case

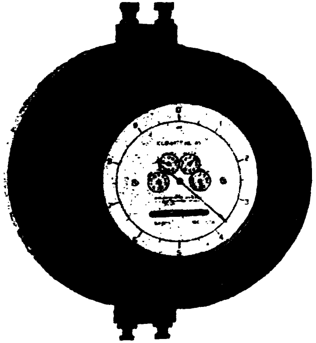


FIG. 655.—Westinghouse, Type C, Switchboard Single-phase Induction Watthour Meter.

is built to conform in appearance to the round type indicating switchboard instrument. There are five dials. The first dial is large, permitting the meter to be read at a distance, and with greater accuracy.

The meter is wound with 5-ampere current coils and 100-volt voltage coils, adapting it for use with transformers of various ratios. Meters used without potential transformers can be supplied with voltage coils up to 500 volts.

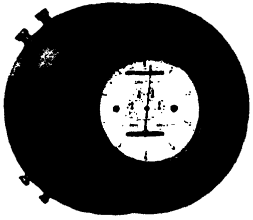
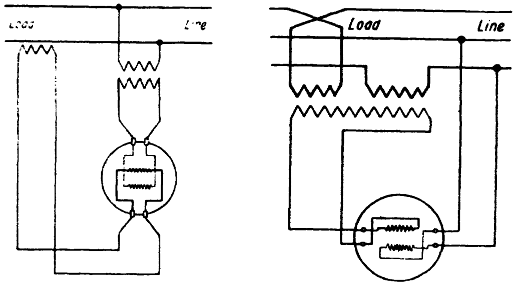
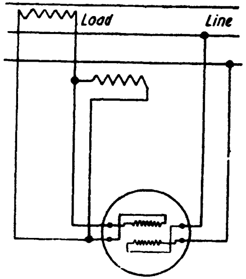


FIG. 656.—External View of Westinghouse, Type C, Switchboard Polyphase Induction Watthour Meter.



a
Front-connected, with Voltage and Current Transformers

b
Rear-connected, with 3-wire Current Transformer



c
Rear-connected, with Two 2-wire Current Transformers

FIG. 658.—Diagrams of Connections, Type C, Metal Cover Single-phase Switchboard Meters.

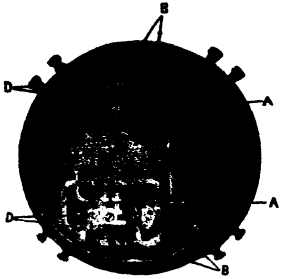
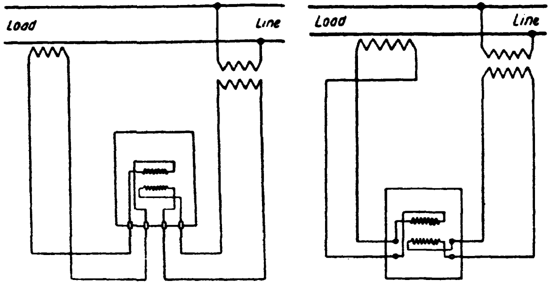


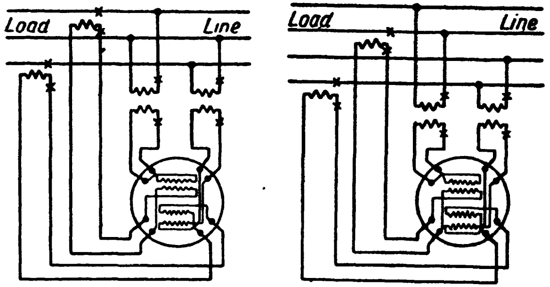
FIG. 657.—Internal View of Westinghouse, Type C, Switchboard Polyphase Induction Watthour Meter.



a
Front-connected, with Voltage and Current Transformers

b
Rear-connected with Voltage and Current Transformers

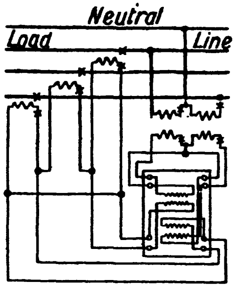
FIG. 659.—Diagrams of Connections, Type C, Glass Cover Single-phase Switchboard Meters.



a
2- or 3-phase, 3-wire

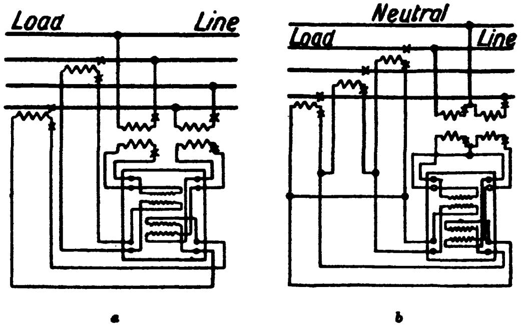
b
2-phase, 4-wire

FIG. 660.—Diagrams of Connections, Type C Metal Pattern Polyphase Switchboard Meters, with Current and Voltage Transformers. Front- or Rear-connected.



3-phase, 4-wire

FIG. 661.—Diagram of Connections, Type C, Metal Pattern Polyphase Switchboard Meters, with Current and Voltage Transformers. Front- or Rear-connected.



a
Rear-connected, 2-phase, 4-wire

b
Rear-connected, 3-phase, 4-wire

FIG. 662.—Diagrams of Connections, Westinghouse Type C, Glass Covered Polyphase Switchboard Meters with Current and Voltage Transformers.

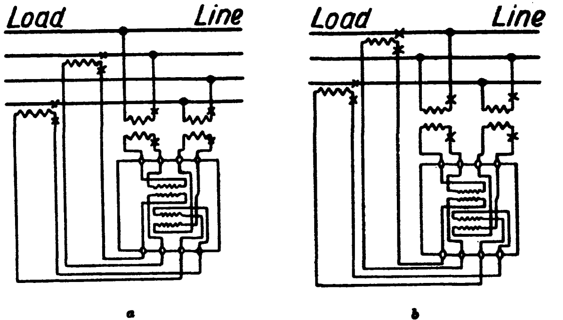
Type RA Recording Demand Watthour Meter.—The Type RA Recording Watthour Demand Meter is designed to register both the kilowatthour consumption and kilowatt demand. The latter is recorded on a moving paper chart so that time and quantity of demand are shown. The recording pen is driven mechanically from the watthour meter gear train so that the rate of movement of the pen across the paper is proportional to the energy registered by the watthour meter.

The watthour meter element is similar to that of the Type OA watthour meter.

This meter is furnished in polyphase types only. Its connections are similar to those of polyphase type OA meters as given in figure 653.

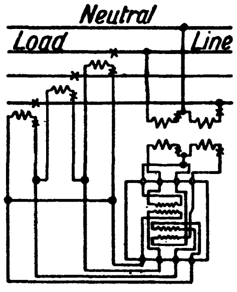
Type RO, Watthour Demand Meter.—This meter records both the kilowatthours consumed and the maximum demand in kilowatts. In general appearance it resembles the standard type OA watthour meter and is installed in the same way, requiring no additional apparatus or wiring.

Type OA Demand Watthour Meter.—The type OA demand meter consists of a watthour meter of the OA type, to which is attached a register which combines a kilowatthour and a kilowatt demand meter of the block interval type. The standard constants and gear ratios of Type OA meters given in Tables 109, 110 and 122 apply to the watthour element of these meters, and their connections are the same as those of corresponding types of watthour meter.



a
Front-connected, 2-phase, 4-wire

b
Front-connected, 2- or 3-phase, 3-wire



c
Front-connected, 3-phase, 4-wire

FIG. 663.—Diagrams of Connections, Westinghouse Type C, Glass Covered Polyphase Switchboard Meters, with Current and Voltage Transformers.

General Notes on Westinghouse Induction Meters.—On all Westinghouse meters, full-load adjustment is made by moving the permanent magnet toward or away from the disk-shaft.

Weakening of the drag magnets tends to make the meter run fast. Defects that would tend to make the meter run slow are: any mechanical interference between rotating parts and stationary parts, foreign matter in the air gap of the drag magnets, defective bearings or registers, short-circuited current coil, or, in the type B, C and OA meters, short circuit in the portion of the current coil on the right-hand current pole (right-hand looking at the face of the meter) or open circuit in the right-hand light-load adjustment loop.

Defects that would tend to make the meter run fast are: short-circuits in the portion of the current coil on the left-hand current pole (left-hand, looking at face of meter), or open circuit in the left-hand light-load adjustment loop.

The continuous overload capacity of these watthour meters is 50 per cent.

Instructions are pasted on the back of the meter and on the inside of the terminal cover.

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